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1312	9—8*	*For* "3 : 4-dimethoxyphenyl or 3 : 4-methylenedioxyphenyl" *read* "3 : 4-dimethoxybenzyl or 3 : 4-methylenedioxybenzyl."
1576	24	*For* "F. C. McQUILLIN" *read* "F. J. McQUILLIN."

* From bottom.

218. *Mechanism of Polymerisation. Part I. Dimeric Tetramethylethylene.*

By HENRY BRUNNER and ERNEST HAROLD FARMER.

THE low-molecular polymerides of mono-olefinic substances appear from the few examples which have been investigated to be composite in character, the number of isomeric forms probably increasing rapidly with increase in polymeric complexity. The structural variation amongst the isomeric products at the different polymeric stages has been insufficiently determined in any example or group of examples to allow of the mechanism of low-molecular polymeric addition being clearly recognised, and at present interest centres on the discovery of a hypothesis of addition which will account for *all* the different isomeric structures which can be shown to occur in the dimeric, trimeric, etc., products, and especially on determining the adequacy of the three reaction-mechanisms at present in the field (see Farmer, *Ann. Reports*, 1935, **32**, 250), *viz.*, those involving (i) hydrogen separation, (ii) alkyl and/or hydrogen separation (Kline and Drake, *J. Res. Nat. Bur. Stand.*, 1934, **13**, 705), and (iii) addition, loss, and migration of charged atoms or groups (Whitmore, *Ind. Eng. Chem.*, 1934, **26**, 94).

The present work began with the desire to study under the mildest possible conditions of reaction the capacity for polymerisation of a simple olefin which contained *no* hydrogen atom capable of transference in the manner envisaged by the hydrogen-separation hypothesis. Tetramethylethylene was the hydrocarbon selected, for in this example an additive mechanism analogous to that which has been postulated for ethylene, *viz.*, $CH_2{:}CH_2 + H - CH{:}CH_2 \longrightarrow CH_3{\cdot}CH_2{\cdot}CH{:}CH_2$, is impossible unless isomerisation (or equivalent structural modification) of the addendum-molecule precedes addition. As regards the probability of such isomerisation occurring independently of the polymerisation process, it is sufficient to say that the hydrocarbon possesses a very considerable degree of stability towards heat alone, although at 300° in the presence of a phosphoric oxide–silica gel catalyst tetramethylethylene and its two isomerides have been found by Laughlin, Nash, and Whitmore (*J. Amer. Chem. Soc.*, 1934, **56**, 1395) to undergo interconversion in the sense :

$$\underset{(ca.\ 3\%.)}{CMe_3{\cdot}CH{:}CH_2} \rightleftharpoons \underset{(ca.\ 61\%.)}{CMe_2{:}CMe_2} \rightleftharpoons \underset{(ca.\ 31\%.)}{CHMe_2{\cdot}CMe{:}CH_2}$$

The accumulation of alkyl groups on the ethylenic carbon atoms of tetramethylethylene might perhaps be expected to entail a predisposition towards alkyl migration, but it was hoped to avoid complications of this kind by refraining from using sulphuric acid or other strong acid as polymerising agent.

Most methods for the preparation of tetramethylethylene based on elimination reactions involve the formation of some substantial proportion of *as.*-methyl*iso*propylethylene, with possibly traces of *tert.*-butylethylene. A very satisfactory product, however, was obtained by systematic fractionation of the mixture of tetramethylethylene and *as.*-methyl*iso*propylethylene obtained by dehydration of dimethyl*iso*propylcarbinol with oxalic acid (compare Schurman and Boord, *J. Amer. Chem. Soc.*, 1933, **55**, 4930) and with this it was speedily found that the absence of a free hydrogen atom from the ethylenic carbon atoms of tetramethylethylene by no means rendered the hydrocarbon immune from polymerisation; indeed, after trials with various catalysts, boron trifluoride was selected as a suitable agent for promoting reaction at low temperatures with formation of a high yield of dimeride and lesser yields of higher polymerides.

Only the dimeric portion of the product from tetramethylethylene has been studied, and on the scale of experimentation available to us it has been possible to achieve only a partial determination of the nature of the dodecenes contained therein. Ozonolysis of the dimeric portion yielded a variety of aldehydes, ketones and acids, amongst which the following products were recognised : (I) Methyl*iso*propylacetaldehyde ($CHMe_2{\cdot}CHMe{\cdot}CHO$), (II) methyl *tert.*-butyl ketone ($CMe_3{\cdot}COMe$), (III) acetone, (IV) formaldehyde, and (V)

a C_9-ketone (C_7H_{15}·COMe). In addition to these there was a quantity of a somewhat impure C_6-fatty acid, which by careful comparison of its well-crystallised derivatives with those of synthetic isomeric C_6-fatty acids of similar melting point was found to consist substantially of *dl*-methyl*iso*propylacetic acid, doubtless derived by further oxidation of the corresponding aldehyde; furthermore there was present a very small amount of an as yet unidentified C_6- or C_7-fatty acid which yielded an anilide, m. p. 109°.

The products (I) and (II) constituted by far the largest proportion (on a rough estimate at least 70%) of the total ozonolysis product, and since they are complementary to one another as regards the size of their carbon skeletons, they represented with little doubt the fission products of one and the same C_{12}-hydrocarbon, *viz.*, $CHMe_2$·CHMe·CH:CMe·CMe_3. As regards the remaining fission products it appears probable that the C_9-ketone (methyl heptyl ketone) and acetone, both present in the ozonolysis product in minor but substantial proportions, were also complementary, being derived from a hydrocarbon C_7H_{15}·CMe:CMe_2, the nature of the heptyl group in which is undetermined.* The significance of the formaldehyde present in the ozonolysis product is in considerable doubt: the amount was very small indeed, and although it may be derived from a dodecen containing the group >C:CH_2, which is present in the dimeride in very small proportion, it is equally possible that it represents merely a trace of abnormal oxidation product.

The bulk of the dimeride consists, then, of the hydrocarbon $CHMe_2$·CHMe·CH:CMe·CMe_3, and for the building up of the latter, two of the above-mentioned hypotheses (those involving mere hydrogen separation and alkyl separation in the addendum molecule) appear totally inadequate to account. The result also shows that even under conditions of polymerisation which to outward appearance are extremely mild, extensive rearrangement of the carbon skeletons involved can take place with ease. Now an important feature of Whitmore's hypothesis is that it provides a simple mechanism for a wide variety of skeletal rearrangements which, apart from the mechanism, appear to be of the most drastic character. Whitmore's hypothesis can account for the appearance of the hydrocarbon $CHMe_2$·CHMe·CH:CMe·CMe_3, and may well cover the formation of all the various dimeric forms of tetramethylethylene which appear in practice, but at present it is somewhat difficult to forecast which out of the numerous isomeric forms that are possible under the hypothesis will actually appear.

In the course of this work it has been necessary to synthesise most of the isomeric forms of hexaldehyde and to obtain three solid derivatives from each for purposes of comparison. Although many of these derivatives had previously been obtained, the melting points in a number of cases required revision. Six of the eight isomeric hexoic acids were also synthesised, but in this case no substantial differences in the melting points of their derivatives from those recorded in the literature were observed.

Experimental.

Tetramethylethylene.—It was essential for the purposes of the investigation to obtain this hydrocarbon quite free from its isomerides, *as.*-methyl*iso*propylethylene and *tert.*-butylethylene. Anhydrous pinacol was converted by the action of phosphorus tribromide into the corresponding dibromide (Couturier, *Ann. Chim. Phys.*, 1892, **26**, 433), and this debrominated as recommended by Thiele (*Ber.*, 1894, **27**, 455). The olefin obtained was fairly pure after several fractionations, but the yield was only 30%.

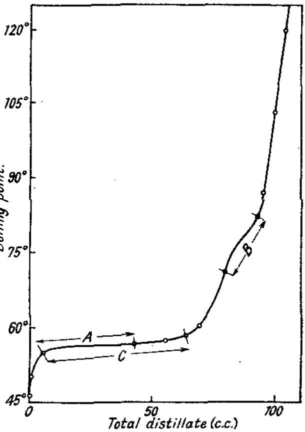
Dimethyl*iso*propylcarbinol, b. p. 117·5—119·5°/765 mm., was smoothly obtained from *iso*propylmagnesium bromide and acetone under the conditions described for the analogous preparation of methyl*iso*propylcarbinol ("Organic Syntheses," XII, 48). Dehydration by means of the catalysts employed by Henry (*Compt. rend.*, 1907, **144**, 552), Kishner and Chonin (*J. Russ. Phys. Chem. Soc.*, 1913, **45**, 1770), Couturier (*Bull. Soc. chim.*, 1911, **9**, 899) and Lindner (*Monatsh.*, 1911, **32**, 421) gave mixtures of tetramethylethylene and methyl*iso*propylethylene, and so did Whitmore's modification (*J. Amer. Chem. Soc.*, 1933, **55**, 3809) of Tschugaev's well-known method (together with much polymeride). The method of Kyriakides (*J. Amer. Chem. Soc.*, 1914, **36**, 987) proved too slow for use.

* The number of theoretically possible methyl heptyl ketones is 39, and it has not been possible to synthesise all the necessary reference compounds for identification.

Ultimately oxalic acid was used as dehydrating agent, the procedure of Schurman and Boord (*ibid.*, **1933**, **55**, 4930) being followed, whereby the carbinol yielded a mixture of tetramethylethylene and methyl*iso*propylethylene, together with a little polymeric hydrocarbon. Rigorous fractionation of the mixture (b. p. 54·0—73·2°) over sodium, a jacketed Widmer column being used, gave a very satisfactory separation. From 609 g. of hexylene, 384 g. of pure tetramethylethylene, b. p. 72·9—73·2°/758 mm., were separated (Schurman and Boord give b. p. 72·9—73·2°/760 mm. for tetramethylethylene, and 55·6—56·0°/760 mm. for *as.*-methyl*iso*propylethylene; *tert.*-butylethylene boils at 40·2°/741 mm., Whitmore, *ibid.*, **1934**, **56**, 1395).

To ensure further that the fraction selected contained no substantial proportion of *as.*-methyl*iso*propylethylene, the dibromide of the hydrocarbon was examined for the presence of methyl*iso*propylethylene dibromide. Accurate estimation of the yield of the camphor-like dibromide of tetramethylethylene by weighing the pure recrystallised solid was impossible owing to the excessive volatility of the latter (barely 90% survived evaporation of the solvent and crystallisation), but careful search gave less than 1% of non-volatile liquid impurity which could contain or represent the liquid dibromide of *as.*-methyl*iso*propylethylene.

Polymerisation of Tetramethylethylene.—Boron trifluoride was very effective in inducing polymerisation at low temperatures (*e.g.*, −60°), but a higher proportion of the dimeride could be obtained at somewhat higher temperatures. Several polymerisations were carried out with this catalyst, the largest of these being conducted as follows: Tetramethylethylene (150 g.) was cooled to − 10° in a 1 l. Drechsel bottle and treated with the boron trifluoride evolved from calcium borate (40 g.), calcium fluoride (80 g.), and concentrated sulphuric acid (270 c.c.). The product was kept overnight, freed by means of a water-pump from the excess of catalyst, and distilled under reduced pressure. All the polymerisate, save a small viscous residue (2·5 g.), distilled between 54°/20 mm. and 171°/2 mm. The distillate was washed with water and with aqueous alkali, dried over calcium chloride, and fractionated. The faintly yellow liquid was first separated (partly at atmospheric pressure and partly at 13 mm.) into 14 fractions, a short Vigreux column being used. The fractions were then separately distilled at atmospheric pressure under a 10-inch glass disc column, each fraction being added to the distilling flask when the lower limit of its range of boiling point was equal to the boiling point of the liquid distilling: in this way the number of fractions obtained was the same as in the previous distillation. A third fractionation was performed under reduced pressure, an asbestos-jacketed Widmer column being used, and the fourth and final fractionation again at reduced pressure, through an air-jacketed Widmer column. All four fractionations were performed very slowly, so that the reflux ratio was approximately 10 : 1, the hydrocarbon throughout being distilled over metallic sodium. In this way 128 c.c. of hydrocarbon were obtained, ranging in boiling point between 44°/12 mm. and 123°/0·4 mm., and increasing in viscosity with rise of boiling point; the last few fractions were yellowish. The boiling-point curve in the final fractionation is shown in the figure.



Distillation of dimeric tetramethylethylene at 10—12 *mm.*

Ozonolysis of the Dimeric Fraction.—Two preliminary ozonolyses, each carried out on the *whole* of the dimeric fraction obtained in a small-scale polymerisation of tetramethylethylene, indicated clearly that the dimeric hydrocarbon was heterogeneous in composition. Separate ozonolyses were accordingly carried out on portions of the low- and the high-boiling fractions (indicated by A and B respectively in the foregoing diagram) of a larger-scale polymerisation. All ozonisations were conducted at 0—10° in a fully saturated, light petroleum medium, the ozonides being obtained on removal of the solvent as faintly yellow oils; these were decomposed by warming with water.

Ozonolysis A. The fraction of the dimeride of b. p. 54·9—56·5°/12 mm. (15·3 g.) yielded, after decomposition of the ozonides, aqueous and oily layers. The former gave positive colour tests for formaldehyde and a positive iodoform reaction, but no solid derivative of acetone could be obtained.

The acidic portion of the oily layer yielded on distillation the fractions: (i) b. p. 50—172° (0·65 g.), (ii) b. p. 172—190° (1·70 g.), (iii) b. p. 190—192·5° (1·58 g.), and (iv) a small residue which contained a trace of a solid acid. Of these, (ii) yielded a crude anilide, m. p. 105—115°, and a crude amide melting indefinitely up to 117°, and (iii) yielded an amide, m. p. 121—122°, which gave on analysis figures agreeing fairly closely with those of a C_6-fatty amide (probably the hitherto unknown *dl*-methyl*iso*propylacetamide, since, of the three C_6-amides closest to 122° in melting point, the melting point of this material was definitely depressed a few degrees by two, *viz.*, by authentic *iso*butyl- and *sec.*-butyl-acetamide). This amide also formed with little doubt the chief constituent of the crude amide of fraction (ii).

The neutral portion of the oily layer had a strong camphor-like odour. It was largely or wholly ketonic, but could not be satisfactorily oxidised with sodium hypobromite.

Ozonolysis B. The fraction of the dimeride of b. p. 71—82°/11·5 mm. (4 g.) yielded, after ozonolysis and decomposition, an aqueous layer from which the dimedon of formaldehyde (m. p. 187—190°) was prepared. This layer also gave a positive iodoform reaction, but no solid derivative of acetone could be isolated.

The neutral portion of the oily layer gave on distillation a little low-boiling aldehydic material and a ketone which showed a positive iodoform reaction and possessed a similar camphor-like odour and roughly equivalent boiling point to that obtained in the foregoing ozonolysis. From each of the fractions into which the ketone was divided by distillation a 2 : 4-dinitrophenylhydrazone was obtained, the separate specimens representing in different degrees of purity essentially one compound, melting constantly at 114·5—115·5° when pure, which corresponded in composition to the 2 : 4-*dinitrophenylhydrazone* of a ketone $C_9H_{18}O$ (Found: C, 55·8; H, 6·8; N, 17·3. $C_{15}H_{22}O_4N_4$ requires C, 55·9; H, 6·9; N, 17·4%). No other pure dinitrophenylhydrazone could be isolated.

The acidic portion of the oily layer distilled almost completely at 94°/11 mm., the distillate yielding an amide which after numerous recrystallisations melted at 113·5°, but was still not entirely homogeneous. The recrystallised product nevertheless corresponded approximately in composition to an amide, $C_6H_{13}ON$, and its melting point was not depressed by admixture with the incompletely purified amide of similar melting point obtained in working up the products of the preceding ozonolysis. Although both of these amides (as the results of ozonolysis C served to confirm) with little doubt consisted substantially of *dl*-methyl*iso*propylacetamide, no synthetic specimen of the latter was available for direct comparison at this stage. From the acidic fractions an anilide, m. p. 109°, was also derived *in very small yield*, and this gave analysis figures intermediate between those required by the anilides of a C_6- and a C_7-acid. This derivative was quite different from that previously obtained (a mixture of the two melted at *ca.* 80°), but gave no depression with an anilide (as yet unidentified) of similar melting point, subsequently obtained.

Thus in both ozonolyses, in addition to traces of formaldehyde, considerable quantities of a single C_6-acid appeared to be formed, the purification of which was difficult owing to the presence of minor amounts of one or more other acids. Examination of the different fractions of the distilled acidic products indicated that this C_6-acid occurred in nearly all, and on a rough estimate represented as a fission product probably at least 70% of the dimeric fraction of the hydrocarbon. A C_9-ketone was found among the products of each of the ozonolyses A and B, but it occurred more abundantly in the latter, in which the higher-boiling fraction of the dimeride had been employed. The presence of acetone, although strongly suspected, could not at this stage be definitely confirmed.

Ozonolysis C. A portion of the dimeride (38 c.c.), collected between 54·9° and 58·5°/10·5 mm. (range C in the boiling-point curve above), was ozonised in saturated light petroleum as before. The ozonide was decomposed with 100 c.c. of water, giving a large aqueous layer (105 c.c.) and an oily layer (33 c.c.).

Both formaldehyde and acetone were present in the aqueous layer, the former undoubtedly in extremely small proportion and the latter (see below) in quite appreciable proportion. No accurate estimate, however, of either could be made owing to the presence in the aqueous layer of traces of higher aldehydes and ketones.

The combined aqueous and oily layers were steam-distilled in the presence of excess of alkali in order to drive over the neutral ozonolysis products; the alkaline residue was then acidified

and again steam-distilled to remove the organic acids. The distillates were separately extracted with ether, the extracts dried over sodium sulphate, and the ether cautiously removed under a long column. The neutral and the acidic residues were each fractionated under a short column, the respective fractions shown below being collected.

Neutral ozonolysis products.

Fraction.	B. p.	Weight, g.
C1	40—60° (760 mm.)	0·2
C2	69—90 ,,	0·75
C3	90—100 ,,	1·25
C4	115—120 ,,	1·7
C5	125—140 ,,	1·4
	50—70 (20 mm.)	
C6	70—85 ,,	2·5
C7	85—90 ,,	3·1
C8	95—105 ,,	1·5
C9	Residue	1·25

Acidic ozonolysis products.

Fraction.	B. p.	Weight, g.	Equiv.
C10	24—34° (20 mm.)	0·6	
C11	75—90 ,,	0·3	
C12	90—100 (19 mm.)	1·9	117·1
C13	100—105 (18 mm.)	3·1	121·5
C14	105—111·5 ,,	1·6	126·2
C15	Residue	0·4	

The aqueous liquor left after extraction of the neutral distillate with ether was treated with 2 : 4-dinitrophenylhydrazine sulphate. The solid derivative formed, after fractional precipitation from methanol, followed by crystallisation from ether, melted at 124°. This substance was acetone-2 : 4-dinitrophenylhydrazone (m. p. 124—126°), and its amount quite appreciable. No other pure dinitrophenylhydrazone could be isolated.

Examination of neutral products. The lower fractions (C1—C3) were mainly aldehydic and underwent some oxidation to fatty acids on standing. Solid derivatives formed from the aldehydes were not homogeneous and required repeated crystallisation before constant melting points were attained.

Fraction C3 yielded the following derivatives : (1) A semicarbazone, which after one recrystallisation from methanol formed colourless needles, m. p. 142° ; the amount was insufficient for further purification, but the analysis figures agreed best with those required for the semicarbazone of a C_6-aldehyde or ketone (Found : C, 54·4 ; H, 10·1 ; N, 26·0 Calc. for $C_7H_{15}ON_3$: C, 53·5 ; H, 9·6 ; N, 26·7%). (2) The 2 : 4-dinitrophenylhydrazone of a C_6-aldehyde or ketone, which after several crystallisations from light petroleum melted constantly at 124—125° (Found : C, 51·5 ; H, 5·47 ; N, 19·5. $C_{12}H_{16}O_4N_4$ requires C, 51·4 ; H, 5·7 ; N, 20·0%). Of the recorded C_6-aldehydes and ketones, only two form 2 : 4-dinitrophenylhydrazones melting in the region of 125°, *viz.*, methyl*iso*propylacetaldehyde (m. p. 123°, 124—125°) and methyl *tert.*-butyl ketone or pinacolone (m. p. 123°, 131°). Both of these substances were synthesised, and their dinitrophenylhydrazones prepared, but neither synthetic derivative had the pale yellow colour of the compound derived from the ozonolysis product : the dinitrophenylhydrazone of authentic methyl*iso*propylacetaldehyde formed orange-yellow crystals, m. p. 122° (mixed m. p. with compound from the ozonolysis product, *ca.* 100°) and that of authentic pinacolone formed orange needles, m. p. 125—131° and giving mixed m. p.'s (different mixtures) between 125° and 131°. Both the derivative from the ozonolysis product and the synthetic specimen of pinacolone dinitrophenylhydrazone, however, after melting and resolidifying, were orange in colour and melted at 131° ; moreover, mixtures of the resolidified specimens melted at 131°. This behaviour accords with Whitmore and McLaughlin's discovery (*J. Amer. Chem. Soc.*, **1933**, **55**, 3732) that pinacolone dinitrophenylhydrazone exists in two crystalline modifications, m. p. 125° and 131°, the former passing into the latter on melting ; these authors, however, make no reference to the different colour or crystalline form of the modifications. (3) A dimedon derivative was also obtained (m. p. *ca.* 128°), but in insufficient amount for adequate crystallisation or analysis.

Fraction C4 gave a 2 : 4-dinitrophenylhydrazone, which after crystallisation formed pale yellow needles, m. p. 124°, identical with the low-melting 2 : 4-dinitrophenylhydrazone of pinacolone (m. p. 124°) obtained from fraction C3.

Fractions C5 and C6 both contained aldehydic and/or ketonic material, the former giving a positive iodoform reaction. Neither, however, could be satisfactorily oxidised with sodium hypobromite or yielded solid derivatives with 2 : 4-dinitrophenylhydrazone.

From fraction C7 an oily semicarbazone was obtained. This, when dissolved in methanol and evaporated in a vacuum desiccator, yielded crystals, m. p. 170—172° (Found : C, 60·0 ; H, 10·9. $C_{10}H_{21}ON_3$ requires C, 60·2 ; H, 10·6%). A semi-solid 2 : 4-dinitrophenylhydrazone was also obtained from the fraction. This, after draining, and crystallising alternately from dilute alcohol and light petroleum, yielded orange-yellow plates, melting constantly at 120—

121°. This derivative, although of somewhat similar m. p., was quite different from the dinitrophenylhydrazone (m. p. 125°) obtained from fractions C3 and C4, depressing the m. p. of the latter to 95°. Nevertheless, analysis showed that the dinitrophenylhydrazone was a derivative of a C_6-aldehyde or ketone ($C_6H_{12}O$) (Found: C, 51·2; H, 5·8. $C_{12}H_{16}O_4N_4$ requires C, 51·4; H, 5·8%). Of the two 2 : 4-dinitrophenylhydrazones of C_6-aldehydes and ketones having m. p.'s in the neighbourhood of 121°, *viz.*, those of pinacolone and methyl*iso*propylacetaldehyde, only that of the latter remained as a possibility, and direct comparison of the foregoing specimen with authentic methyl*iso*propylacetaldehyde-2 : 4-dinitrophenylhydrazone (m. p. 122°) showed the two to be unquestionably identical (mixed m. p. 121°).

Fraction C8 yielded an oily 2 : 4-dinitrophenylhydrazone which partly solidified on standing. The solid portion (m. p. 110—112°) after two recrystallisations from light petroleum melted at 120° and was found to be identical with the 2 : 4-dinitrophenylhydrazone obtained from fraction C7.

Acidic products of ozonolysis. These products, save for the small residue, consisted of fatty acids. Titration of representative portions of the fractions C13—C15 with $N/10$-sodium hydroxide showed that the mean molecular weight of fraction C13 corresponded to the value required for a C_6-fatty acid, and those of fractions C14 and C15 lay between those required for C_6- and C_7-acids. The experimental values, however, were likely to be rather high, owing to the presence of traces of non-acidic impurities and of higher acids (*e.g.*, a C_8-acid from the C_9-ketone formed by ozonolysis).

Solid derivatives were prepared, *via* the acid chloride, only from the largest fraction, C13. The amide melted at first at 106—109°, but after five recrystallisations its m. p. was still several degrees below that of pure *dl*-methyl*iso*propylacetamide (m. p. 128—130°), synthesised for the comparison, although it was sufficiently pure to leave no doubt as to its identity with the latter.*

The anilide was obtained as an oil, which, when taken up in light petroleum, partly solidified. The bulk of the solid melted at 80—85°, but it was heterogeneous. A little of an apparently homogeneous anilide, m. p. 107—109°, was isolated, and direct comparison showed that this was neither *iso*butylacetanilide (m. p. 112°) nor *iso*valeranilide (108—111°); it resembled, however, and gave no depression of m. p. with, the anilide, m. p. 109°, isolated in ozonolysis B (p. 1042); moreover, it appeared from its composition to be the anilide of a C_7- rather than of a C_6-acid (Found: C, 76·4; H, 9·1. $C_{12}H_{17}ON$ requires C, 75·4; H, 9·0%. $C_{13}H_{19}ON$ requires C, 76·0; H, 9·3%). The major portion of the solid, however, was not resolved into its components, and rather remarkably no methyl*iso*propylacetanilide was isolated in a reasonably pure condition.

The *p*-toluidide was obtained as an oil, a small proportion of which solidified after distillation. This portion, after crystallisation successively from light petroleum and dilute methanol, melted at 128·5—130·5°, but was not identified.

Isomeric Hexaldehydes.—Six of the eight theoretically possible hexaldehydes have been synthesised for purposes of comparison, although only one of these (*dl*-methyl*iso*propylacetaldehyde) was hitherto unknown. The m. p.'s of the new derivatives and the amended m. p.'s of known derivatives (where these were found to be inaccurate) are shown in the table in heavy type. Brief details of the synthetical methods found to be most satisfactory are given below.

Aldehyde.	Formula.	B. p.	2 : 4-Dinitrophenylhydrazone, m. p.	Semicarbazone, m. p.	Dimedon derivative, m. p.
n-Hexaldehyde	$CH_3\cdot[CH_2]_4\cdot CHO$	131°	104°	114·5—115·5° (106)	108·5°
Methylpropyl-acetaldehyde	CHMePr·CHO	119—121	103	100—102	—
*iso*Butyl- ,,	$CHMe_2\cdot[CH_2]_2\cdot CHO$	121	**99**	**126·5—127·5**	**133**
sec.-Butyl- ,,	$CHMeEt\cdot CH_2\cdot CHO$	—	**93·5—94·5**	128—129	**144**
dl-Methyl*iso*propyl- ,,	$CHMe_2\cdot CHMe\cdot CHO$	**115—117**	**123—123·5**	**110—111**	**162**
l- ,, ,, ,,	,,		124—125	128—129 *	—
Diethyl- ,,	$CHEt_2\cdot CHO$	117—119	**94·5—95**	**97·5—99·5**	**102—102·5**
Dimethylethyl- ,,	$CMe_2Et\cdot CHO$	102—104	**145**	154—156	**118—120**
tert.-Butyl- ,,	$CMe_3\cdot CH_2\cdot CHO$	102—104	147—147	—	167

* Inactive racemised form, m. p. 109—110°.

iso*Butylacetaldehyde.* The general method of aldehyde synthesis described by Wood and Comley (*J. Soc. Chem. Ind.*, 1923, **42**, 429T) worked well in this case. To an ethereal solution of

* In the earlier stages of the purification, identification with *iso*butylacetamide (m. p. 118—119°) appeared a possibility, since mixtures of *iso*butylacetamide and methyl*iso*propylacetamide show no marked depression of m. p.

*iso*amylmagnesium bromide, formed from magnesium (2/3 mol.) and primary *iso*amyl bromide (2/3 mol.), an ethereal solution of ethyl orthoformate (1/3 mol.) was gradually run in at a rate which promoted gentle refluxing. This operation took 20 minutes, and refluxing was continued for a further 2 hours, a white precipitate separating. The bulk of the ether was distilled off, and the liquid residue (resolidifiable on cooling) kept overnight and decomposed by ice-water. The diethylacetal of *iso*butylacetaldehyde, $CHMe_2\cdot[CH_2]_2\cdot CH(OEt)_2$, so obtained, boiled at 105—110°/18 mm., but mainly at 107·5°/18 mm. (Tschitschibabin, *Ber.*, 1904, **37**, 188, gives b. p. 180—182°). Yield, 86%. The acetal (20 c.c.), heated to 120° with 5*N*-sulphuric acid (60 c.c.), gave the aldehyde, which was purified through its bisulphite compound. The thoroughly dried, distilled aldehyde yielded the 2 : 4-dinitrophenylhydrazone in golden-yellow prisms, m. p. 99°, from light petroleum (Found : C, 51·8; H, 5·3. Calc. for $C_{12}H_{16}O_4N_4$: C, 51·4; H, 5·8%), the semicarbazone in lustrous plates, m. p. 126·5—127·5°, from methanol (Found : C, 53·4; H, 9·4. Calc. for $C_7H_{15}ON_3$: C, 53·5; H, 9·6%), and the dimedon in lustrous crystals from dilute methanol, m. p. (before and after sublimation) 133° (Found : C, 73·0; H, 9·2. Calc. for $C_{22}H_{34}O_4$: C, 72·85; H, 9·5%).

sec.-*Butylacetaldehyde*. The method of Stephen (J., 1925, **127**, 1874), starting from *sec.*-butylacetamide, and the method of Sabatier (*Compt. rend.*, 1912, **154**, 561), depending on the catalytic reduction of *iso*butylacetic acid, gave poor results. Distillation of the mixed barium salts of *sec.*-butylacetic acid (p. 1046) and formic acid furnished an oily aldehyde, which was dried, distilled, and converted into its bisulphite compound. The regenerated aldehyde gave a 2 : 4-*dinitrophenylhydrazone*, which separated in pale golden-yellow crystals, m. p. 93·5—94·5°, from light petroleum (Found : C, 50·7; H, 5·6. $C_{12}H_{16}O_4N_4$ requires C, 51·4; H, 5·8%), and a semicarbazone, crystallising from light petroleum in colourless prisms, m. p. 128° (Stevens, *J. Amer. Chem. Soc.*, 1935, **57**, 1115, gives m. p. 128—129°). The dimedon derivative (too small in amount for analysis) crystallised from methanol in colourless prisms, m. p. (unsharp) 144°, unchanged by sublimation.

dl-*Methyl*iso*propylacetaldehyde*. The mixed barium salt method gave an unsatisfactory result.

(1) Methyl *iso*propyl ketone [b. p. 94°/740 mm.; 2 : 4-dinitrophenylhydrazone, m. p. 122—122·5° (Allen, *J. Amer. Chem. Soc.*, 1930, **52**, 2955, gives m. p. 117°); semicarbazone, m. p. 112—113° (Bardan, *Bull. Soc. chim.*, 1931, **49**, 1875, gives m. p. 112°)], obtained in good yield by the method of Whitmore, Evers, and Rothrock ("Organic Syntheses," **13**, 68), was converted into ethyl β-methyl-β-*iso*propylglycidoacrylate, $CHMe_2\cdot CMe\cdot CH\cdot CO_2Et$ (with O bridging CMe and CH), by Rutovski and Daiev's procedure (*Ber.*, 1931, **64**, 697) for preparing glycidic esters. The interaction between the ketone and ethyl chloroacetate in presence of sodium proceeded smoothly, the product yielding much unchanged chloroacetic ester and a slightly yellowish-green oil, b. p. 203—213°. The latter (10 g.), consisting essentially of the glycidic ester, was mixed with a solution of sodium ethoxide (1·34 g. of sodium; 20 g. of alcohol), and the product treated dropwise with a little water (1·05 g.). The hydrolysis of the ester, thus begun, was completed on a steam-bath overnight. The alkaline hydrolysis product was steam-distilled to remove alcohol and unchanged ester, and then treated with excess of sulphuric acid. The acid product was heated to boiling to decompose the free glycidic acid and then steam-distilled. The hitherto unknown dl-*methyl*-iso*propylacetaldehyde* passed over and was further purified by conversion into its sodium bisulphite compound. The regenerated aldehyde, b. p. 115—117°/770 mm., yielded a 2 : 4-*dinitrophenylhydrazone*, m. p. 121—123·5° (Found : C, 52·0; H, 5·8. $C_{12}H_{16}O_4N_4$ requires C, 51·4; H, 5·75%), a *semicarbazone*, m. p. 110—111° (Found : C, 53·5; H, 9·4. $C_7H_{15}ON_3$ requires C, 53·5; H, 9·6%),* and a *dimedon*, m. p. 162° (Found : C, 72·7; H, 9·6. $C_{22}H_{34}O_4$ requires C, 72·85; H, 9·5%).

(2) Methyl*iso*propylacetic acid, b. p. 100—103°/14 mm., was esterified with alcoholic sulphuric acid, the pleasant-smelling ethyl ester boiling at 149—153°/760 mm. (Gorski, *J. Russ. Phys. Chem. Soc.*, 1913, **45**, 168, gives b. p. 148—150°/745 mm.). This ester (8·5 g.), dissolved in absolute alcohol (34 c.c.), was reduced by addition of sodium (8·1 g.) at a rate sufficient to sustain gentle ebullition. The product was kept at 120—165° for 4 hours, cooled, and decomposed by water. The resulting clear liquor was steam-distilled until it became cloudy through

* Reindel and Kipphan (*Annalen*, 1932, **493**, 181) have obtained *l*-methyl*iso*propylacetaldehyde by the ozonolysis of ergosterol, which yields a *l*-2 : 4-dinitrophenylhydrazone, m. p. 124—125°, and a *l*-semicarbazone, m. p. 128—129°. Racemisation of the *l*-semicarbazone gave an inactive derivative, m. p. 109—110° (Guiteras, *Annalen*, 1932, **494**, 116).

precipitation of *iso*hexyl alcohol. The latter was extracted with ether, dried (anhydrous sodium sulphate), recovered (2 g.), and oxidised by potassium dichromate and sulphuric acid. The escaping methyl*iso*propylacetaldehyde was collected, dried, and used for the formation of the derivatives described in (1).

Diethylacetaldehyde. Diethylcarbinol, b. p. 114—117°/755 mm., was converted into bromodiethylmethane by means of hydrobromic acid (*d* 1·49), and the bromo-compound, after purification in the usual way (b. p. 116—122°/756 mm.), dried by distillation over potassium carbonate. By interaction of this bromide with magnesium and ethyl orthoformate the diethylacetal of diethylacetaldehyde was formed (compare p. 1045). The crude acetal gave on distillation the fractions, (i) b. p. 60—80°/16 mm., (ii) 80—90°/15 mm., (iii) 90—125°/14 mm., and (iv) b. p. above 125°/14 mm., of which (ii) consisted of almost pure acetal and gave a good yield of aldehyde on hydrolysis. The latter was converted into its bisulphite compound, and the regenerated aldehyde used directly in forming derivatives. The 2 : 4-*dinitrophenylhydrazone* formed pale orange plates, m. p. 94·5—95°, from light petroleum (Found: C, 51·5; H, 5·3. $C_{12}H_{16}O_4N_4$ requires C, 51·4; H, 5·7%), the semicarbazone, colourless prisms, m. p. 97·5—99·5°, from benzene–light petroleum (Sou Phou Ti, *Compt. rend.*, 1931, **192**, 462, gives m. p. 95°) (Found: C, 53·9; H, 9·4. Calc. for $C_7H_{15}ON_3$: C, 53·5; H, 9·6%), and the *dimedone*, colourless prisms from methanol, m. p. 102—102·5° (Found: C, 73·0; H, 9·2. $C_{22}H_{34}O_4$ requires C, 72·9; H, 9·5%).

Dimethylethylacetaldehyde. This aldehyde was not formed by interaction of *tert.*-amylmagnesium chloride with orthoformic ester, but a small yield was obtained by interaction of the same Grignard reagent with ethyl formate.

Favorski (*J. Russ. Phys. Chem. Soc.*, 1918, **50**, 43; *Centr.*, 1923, III, 667) records having obtained *tert.*-amylcarbinol from the latter two reactants, but gives no details of the reaction. Normally the diamyl derivative $(CMe_2Et)_2CH{\cdot}OH$ might be expected to arise, but Bouveault (*Compt. rend.*, 1904, **138**, 1108), through an analogous reaction between *tert.*-butylmagnesium chloride and methyl formate, conducted at − 10° to − 15°, reports having obtained *tert.*-butylcarbinol together with a small quantity of *tert.*-butylacetaldehyde.

The Grignard reagent was formed from 20 g. of *tert.*-amyl chloride and 5 g. of magnesium, 0·2 c.c. of ethyl bromide being used to start the reaction (iodine for this purpose is unsatisfactory). To it, cooled in ice-salt, 6 g. of freshly purified ethyl formate (b. p. 54·5°/773 mm.) were added. The white addition compound was left over-night, decomposed with water, and worked up in the usual way. The product was distilled and collected in four fractions, (i) b. p. 44—108°, (ii) b. p. 108—120°, (iii) b. p. 124—140°, and (iv) b. p. 160—168°. Fraction (i) contained free dimethylethylacetaldehyde: from this were obtained (1) a pale orange 2 : 4-*dinitrophenylhydrazone*, m. p. 145° after two recrystallisations from light petroleum (Found: C, 51·6; H, 5·3. $C_{12}H_{16}O_4N_4$ requires C, 51·4; H, 5·75%), (2) a semicarbazone, m. p. 153·5° (Favorski, *loc. cit.*, gives 154—156° as the m. p. of dimethylacetaldehydesemicarbazone), and (3) a *dimedone*, m. p. 118—120° after crystallisation from dilute methanol (Found: C, 72·5; H, 9·2. $C_{22}H_{34}O_4$ requires C, 72·85; H, 9·45%). Fraction (ii) yielded 2 g. of *tert.*-amylcarbinol.

Isomeric Hexoic Acids.—Of the eight isomeric hexoic acids, six were synthesised for purposes of comparison by the excellent method of Hommelen (*Bull. Soc. chim. Belg.*, 1933, **42**, Nos. 5—6). From these the required amides and anilides were readily obtained in pure condition, the m. p.'s not differing substantially from those recorded by Hommelen. For derivatives of *n*-hexoic acid and methylpropylacetic acid, the m. p.'s given by Beilstein (" Organische Chemie ") and by Hommelen respectively were accepted.

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219. *Complex Fluorides of Gallium and the Alkali Metals.*

By W. Pugh.

The formation of stable complex compounds is a characteristic of elements of weak electropositiveness. The tendency to co-ordinate, however, diminishes as the electropositiveness of the central atom increases. So, although boron and aluminium form stable complex

fluorides, the other members of the group should form them with increasing difficulty. Of these other members, little is known. One complex gallium fluoride, $3NH_4F,GaF_3$ (Hannebohn and Klemm, *Z. anorg. Chem.*, 1936, **229**, 341), and one complex indium fluoride, $3NH_4F,InF_3$ (Huysse, *Z. anal. Chem.*, 1900, **39**, 9) have been described. Thallic fluoride has apparently not been prepared, but Gewecke (*Annalen*, 1909, **366**, 217) isolated $KF,2TlF_3$. As expected, however, this is unstable, being decomposed by water into thallic hydroxide and hydrofluoric acid.

It is here shown that gallium forms complex fluorides with all the alkali-metal fluorides. The series is of interest, for it clearly shows, for a single element, the effect of the atomic volume of the co-ordinated molecules on the number of such molecules co-ordinated. The *compounds* now described are : $3LiF,GaF_3$; $3NaF,GaF_3$; $3NH_4F,GaF_3$; $2KF,GaF_3,H_2O$; $RbF,GaF_3,2H_2O$; and $CsF,GaF_3,2H_2O$. They are all sparingly soluble in water, and are precipitated when solutions of their components are mixed. They form semi-gelatinous but dense precipitates, which on drying yield fine white powders. The potassium and the ammonium compound crystallise well, but the others form microcrystalline powders too irregular in shape to be characterised.

EXPERIMENTAL.

The gallium was obtained from germanite by a method shortly to be described. It was believed to be spectroscopically pure, since its spectrum showed no lines which could be definitely attributed to any other element.

Methods of Analysis.—Estimations of gallium and alkali metal were always made on the same weighed sample, which was first heated to fuming with sulphuric acid in a small platinum crucible in order to remove hydrogen fluoride. From the clear acid extract of the residue, gallium hydroxide was precipitated with ammonia at the neutral point to methyl-red, paper pulp being added to facilitate filtration, and the precipitate was washed with a dilute solution of ammonium nitrate, charred, and ignited to the oxide. The alkali metal was weighed as sulphate after evaporation of the filtrate and ignition of the residue. In this way concordant results were always obtained, but estimations attempted without previous removal of hydrogen fluoride gave low and variable values.

The fluoride content was determined in a separate sample by precipitation as lead chlorofluoride, followed by volumetric estimation of chlorine in the precipitate (Hillebrand and Lundell, " Applied Inorganic Analysis," p. 605). The method gave good results.

Preparation of Gallium Fluoride, $GaF_3,3H_2O$.—Ignited gallium oxide is insoluble in hydrofluoric acid. Johnson and Parsons (*J. Physical Chem.*, 1932, **36**, 2591), however, prepared gallium fluoride in two ways : (*a*) by dissolving the metal in 40% hydrofluoric acid, (*b*) by dissolving gallium hydroxide in dilute hydrofluoric acid. The first method is very slow, for even in contact with platinum no more than 2 g. of the metal will dissolve in a day. The second method involves the solution of the metal and the precipitation and washing of the hydroxide. A more convenient method consists in evaporating the nitrate solution with hydrofluoric acid. Nitric acid is the best solvent for the metal. 5 G. of gallium metal were dissolved in concentrated nitric acid in a flask heated on the water-bath. The syrupy liquid was transferred to a platinum basin, evaporated with hydrofluoric acid, and the evaporation repeated three times with small amounts of hydrofluoric acid. The residue was finally dried on the water-bath to a fine white powder (Found : Ga, 38·4; F, 31·45. Calc. : Ga, 38·6; F, 31·5%); yield, 12·90 g. (Calc. for $GaF_3,3H_2O$, 12·96 g.).

Sodium Gallifluoride, $3NaF,GaF_3$.—Theoretical quantities of hydrated gallium fluoride (3·614 g.) and of pure anhydrous sodium carbonate (3·18 g.) were dissolved separately in about 40 c.c. of dilute hydrofluoric acid, and the solutions mixed. A gelatinous but heavy precipitate appeared. The liquid was evaporated on the water-bath to about 10 c.c., cooled, and decanted. The residue was washed by decantation with cold water and finally by centrifuging, and dried in the air (Found : Na, 26·7; Ga, 27·7; F, 45·2. $3NaF,GaF_3$ requires Na, 27·3; Ga, 27·6; F, 45·1%); yield, 4·9 g. (Calc. : 5·05 g.). *Sodium gallifluoride* is a fine white powder which remains unchanged on long standing in air. In crystallising slowly from water, it forms clusters of tiny crystals, which, however, are too indefinite in outline to be classified.

Ammonium Gallifluoride, $3NH_4F,GaF_3$.—The existence of this complex salt (Hannebohn and Klemm, *loc. cit.*) is now confirmed. It may be made by substituting ammonium fluoride for sodium fluoride in the foregoing preparation (Found : NH_4, 22·75; Ga, 29·2; F, 48·2. Calc. :

NH_4, 22·7; Ga, 29·3; F, 48·0%). This compound is evidently more soluble than the sodium compound, for the yield obtained was poorer and the product was definitely crystalline. It recrystallises well in small but well-formed octahedra. It is stable in air at the ordinary temperature, and decomposes on heating in moist air with loss of ammonium fluoride and hydrogen fluoride. The loss in weight of 0·44 g. at 380° was 0·18 g., and the residue (Found: Ga, 56·0; F, 26·6%) was evidently a mixture of fluoride and oxide.

Lithium Gallifluoride, $3LiF,GaF_3$.—Lithium carbonate (0·60 g.), dissolved in about 200 c.c. of hot dilute hydrofluoric acid, and a solution of gallium fluoride (1·00 g.) were mixed. A slight turbidity appeared, and the liquid was evaporated to dryness. After standing for some time with about 30 c.c. of hot dilute hydrofluoric acid, the granular residue was washed well and dried in the air to constant weight; yield, 1·05 g. (Found: Li, 10·3; Ga, 33·5; F, 55·4. $3LiF,GaF_3$ requires Li, 10·2; Ga, 34·1; F, 55·7%). *Lithium gallifluoride* is a snow-white micro-crystalline powder. Attempts to define the form of the crystals by slow crystallisation on a glass slide were unsuccessful.

Potassium Gallifluoride, $2KF,GaF_3,H_2O$.—This was prepared from solutions of gallium fluoride (3 g.) and an excess of potassium fluoride obtained from pure anhydrous potassium carbonate (4 g.). The liquid was evaporated to about 20 c.c., cooled, and decanted. The gelatinous heavy residue was washed by decantation and several times by centrifuging, and finally dried in the air; yield, 4·3 g. (Found: K, 29·7; Ga, 26·6; F, 36·5. $2KF,GaF_3,H_2O$ requires K, 30·0; Ga, 26·7; F, 36·4%). The crystals consist of what appear to be rhombs with an occasional swallow-tail twin. They are anisotropic and extinction is not always parallel. They are probably monoclinic. They are stable at 110°, but at 230° they lose $1H_2O$ (Loss: 7·0. Calc.: 6·9%). The anhydrous salt so formed underwent no change in weight on standing in air for 10 days.

Rubidium Gallifluoride, $RbF,GaF_3,2H_2O$.—Gallium fluoride (1·0 g.) and rubidium chloride (0·66 g.) were dissolved separately in dilute hydrofluoric acid and mixed. The solution was evaporated on the water-bath, more hydrofluoric acid added, and the solution again taken to dryness. The residue was extracted and well washed with water (5 c.c. at a time), and dried at 110° (Found: Rb, 31·8; Ga, 26·2; F, 28·0. $RbF,GaF_3,2H_2O$ requires Rb, 32·0; Ga, 26·1; F, 28·4%). The crystals lose $2H_2O$ (Loss: 13·5. Calc.: 13·5%) at 230°, and the anhydrous salt on standing in air reabsorbs half of this water in 2 days. Thereafter there is no appreciable change in the course of 10 days.

Cæsium Gallifluoride, $CsF,GaF_3,2H_2O$.—This complex salt was made from gallium fluoride (1 g.) and cæsium chloride (2 g.) in the same manner as the rubidium analogue. It was dried at 110° (Found: Cs, 42·0; Ga, 22·25; F, 24·2. $CsF,GaF_3,2H_2O$ requires Cs, 42·25; Ga, 22·15; F, 24·15%). All the water is lost at 230°, but half of it is recovered rapidly in air, and there is a subsequent slow increase in weight, 80% of the loss at 230° being recovered in 12 days. Both the rubidium and the cæsium compound are snow-white powders, definitely crystalline, but too irregular to be characterised.

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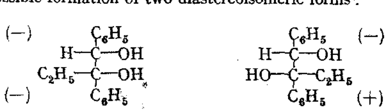
220. *Studies in Stereochemical Structure. Part VIII. The Stereochemical Relationship of the α- and the β-Forms of Substituted Hydrobenzoins.* (a) *Ethylhydrobenzoin (α-Form).*

By ROBERT ROGER.

ACREE (*Amer. Chem. J.*, 1905, **33**, 193) first described the action of ethylmagnesium bromide on benzoin and showed that it gave *r*-ethylhydrobenzoin. McKenzie and Wren (J., 1910, **97**, 473) later synthesised a dextrorotatory ethylhydrobenzoin from *D*(—)benzoin, but foresaw the possible formation of two diastereoisomeric forms:



Only one form was isolated by the latter authors from the Grignard action. Tiffeneau and Lévy (*Bull. Soc. chim.*, 1927, **41**, 1351) found, however, that the action of phenylmagnesium bromide on phenylpropionylcarbinol, $C_6H_5 \cdot CH(OH) \cdot CO \cdot C_2H_5$, gave once again a homogeneous product, but this, though isomeric, was not identical with the glycol isolated by Acree. Later, Roger (*Helv. Chim. Acta*, 1929, **12**, 1060) obtained two optically active ethylhydrobenzoins by the actions of ethylmagnesium bromide and phenylmagnesium bromide on *D*(—)benzoin and *D*(—)phenylpropionylcarbinol respectively. Only one form of the glycol was isolated in each action, and, starting from *D*(—)mandelic acid, both of these forms were dextrorotatory in the solvents examined. The melting points and magnitude of the rotatory powers in various solvents showed that these two forms of the glycol were quite distinct. Similarly, Roger (*Biochem. Z.*, 1931, **230**, 320) examined the forms of methylhydrobenzoin obtained from *D*(—)benzoin and *D*(—)phenylacetylcarbinol and showed, not only that they were quite distinct, but that neither form was identical with the (+)αα-diphenylpropylene-αβ-glycol obtained by the action of phenylmagnesium bromide on (+)ethyl lactate.

		$[\alpha]_{5893}^{20°}$ in	
Glycol.	M. p.	EtOH.	$COMe_2$.
D(+)Methylhydrobenzoin (from phenylacetylcarbinol, α-form)	92—93°	+40·6°	+ 31·1°
D(+)Methylhydrobenzoin [from *D*(−)benzoin, β-form]	80—81	+21·3	+ 30·9
(+)αα-Diphenylpropylene-αβ-glycol	92—93	—	+132·7

This point is important, since it was possible that one of the ketols (particularly the phenylacetylcarbinol) might have undergone rearrangement during the Grignard action, with the resultant formation of some αα-diphenylpropylene-αβ-glycol :

$$CHPh(OH) \cdot CO \cdot CH_3 \longrightarrow CH_3 \cdot CH(OH) \cdot COPh \longrightarrow CH_3 \cdot CH(OH) \cdot C(OH)Ph_2$$

In fact, Favorsky and Temnikova (*Bull. Soc. chim.*, 1935, **2**, 253) found that the methylbenzoylcarbinol, $CH_3 \cdot CH(OH) \cdot CO \cdot C_6H_5$, did undergo transformation during the action of phenylmagnesium bromide, giving a mixture of glycols. They also found, however, that phenylacetylcarbinol was not transformed during the Grignard action.

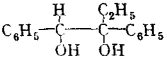
The existence of stereoisomeric forms * of the substituted hydrobenzoins has also been confirmed in the following cases : the *m*- and *p*-tolylhydrobenzoins (McKenzie, Roger, and McKay, J., 1932, 2597 ; Roger and McKay, J., **1933**, 332 ; McKenzie and Kelman, J., 1934, 413), the benzylhydrobenzoins (Roger, *loc. cit.*), the anisylhydrobenzoins (McKenzie and Kelman, *loc. cit.* ; McKenzie, Luis, Tiffeneau, and Weill, *Bull. Soc. chim.*, 1929, **45**, 414) ; and since the work of McKenzie and Wren it has been accepted implicitly that the two forms are diastereoisomers. No proof of this point has ever been brought forward, nor have the actual configurations of any of the forms been determined. Actually, Roger and McKay (*loc. cit.*) showed that the contribution of the new-born centre of asymmetry to the evident rotatory power of the tolylhydrobenzoins (α-forms) was small. This was later confirmed by the fact that phenyl-*p*-tolylglycollic acid has a very small rotatory power (McKenzie, Christie, and Ritchie, J., 1935, 153). The problem of the configuration of the two forms was tackled generally on the principle of converting the mandelyl complex into a symmetric system whilst the new asymmetric system was left unchanged. This was tried in two ways : (1) by conversion of the mandelyl complex into the benzyl system, and (2) by the oxidation of the mandelyl complex to the benzoyl group :

$$Ph \cdot CO \cdot CPhEt \cdot OH \xleftarrow{O} OH \cdot CHPh \cdot CPhEt \cdot OH \xrightarrow{H_2} CH_2Ph \cdot CPhEt \cdot OH$$

The reduction of the glycols was not successful. Reducing agents such as hydrogen and palladium or platinum, or zinc and dilute hydrochloric acid, were without action, and more powerful agents such as hydriodic acid caused dehydration of the glycols and yielded inseparable mixtures of products. At first, oxidation methods were unsuccessful also. Nitric acid caused dehydration of the glycol. No definite results were obtained by the use

* The term " α-form " is applied to the glycol synthesised from the ketol of the smaller molecular weight, the term " β " to that from the ketol of greater molecular weight. Thus the ethylhydrobenzoin derived from phenylpropionylcarbinol is the α-form, and that from benzoin is the β-form.

of osmic acid or alkaline hypobromite. Lead tetra-acetate, chromic acid, aqueous pyridine and copper sulphate all caused scission of the glycol into simpler molecules. Finally, the method used was that of Gomberg and Bachmann (*J. Amer. Chem. Soc.*, 1930, **52**, 4966; see also Shankland and Gomberg, *ibid.*, 1930, **52**, 4973). The glycol was dissolved in ethylmagnesium iodide, and this solution was used to reduce benzaldehyde to benzyl alcohol, the glycol in its turn being oxidised to ethylbenzoin. Thus, the racemic form of ethylhydrobenzoin (α-form) gave *r*-ethylbenzoin, and the *D*(+)ethylhydrobenzoin gave (+)ethylbenzoin:



(I.) (−) (+)

CHPh(OH)·C(OH)PhEt ⟶ CHPh(OMgI)·C(OMgI)PhEt + Ph·CHO
(+)
(α-form.)
↓
COPh·C(OH)PhEt + CH_2Ph(OH)
(+)

From this evidence the α-form of ethylhydrobenzoin would appear to have the structure (I) *provided* that no inversion of the mandelyl complex has occurred either during the conversion of *D*(−)mandelic acid into *D*(+)ethylhydrobenzoin, or in the solution of the glycol in the ethylmagnesium iodide preparatory to oxidation. So far, it has not been found possible to detect whether such an inversion has taken place.

The ethylbenzoin isolated from this action was the optical antipode of that obtained from (+)phenylethylglycollic acid by McKenzie and Ritchie (*Ber.*, 1937, **70**, 23), so the following relationships emerge:

D(−)Mandelic acid ⟶ *D*(−)Phenylpropionylcarbinol
↓
(−)Phenylethylglycollic acid ⟶ (+)Ethylbenzoin ⟵ *D*(+)Ethylhydrobenzoin (α-form)

This does not, however, enable one to connect the configurations of mandelic acid and phenylethylglycollic acid.

McKenzie and Ritchie (*loc. cit.*) observed that their (−)ethylbenzoin (in ethyl alcohol) became dextrorotatory in carbon disulphide. The configuration of the new centre of asymmetry would therefore appear to depend on the solvent used, particularly since the *D*(+)ethylhydrobenzoin (α-form) remains dextrorotatory in carbon disulphide. Roger and McGregor (*J.*, 1934, 1545) found that asymmetric induction played a considerable part in determining the magnitude of rotatory power of *D*(−)benzoin in various solvents, for it

	D(−)Benzoin.	*D*(−)Phenylpropionylcarbinol.	Ethylbenzoin.	
$[\alpha]^{20°}_{5461}$ in EtOH	−162·4°	−199°	+253°	↓ increasing
$[\alpha]^{20°}_{5461}$ in CS_2	−501	−361	−182	lævorotation

showed a striking increase in lævorotation in the passage from ethyl alcohol to carbon disulphide, and the (+)ethylbenzoin isolated here is showing the same tendency. This criticism, therefore, does not render the deductions from this oxidation invalid.

The oxidation of ethylhydrobenzoin (β-form) and other evidence regarding the relationship of the two forms of the glycol will be dealt with in future communications.

Experimental.

Ethylhydrobenzoin (α-form), prepared by the action of phenylmagnesium bromide on *D*(−)phenylpropionylcarbinol, had $[\alpha]^{18°}_{5461}$ + 42·1° (c = 3·278 in benzene, l = 1, $\alpha^{18°}_{5461}$ = + 1·38°).

The glycol (10 g.) was dissolved in the Grignard reagent prepared from ethyl iodide (30 g.). Benzaldehyde (15 g., twice distilled) in 50 c.c. of pure, dry benzene was added gradually. The mixture was kept overnight and then boiled for 1½ hours. On decomposition with ice and sulphuric acid and extraction with ether, an oil was obtained from the ethereal layer, and was distilled in a vacuum. A fraction, b. p. 200—208°/20 mm., was collected which slowly became semi-solid. The addition of light petroleum with a small amount of ethyl alcohol caused separation of more solid. This was recrystallised from light petroleum and alcohol, coarse needles, m. p. 69—71° being formed. After several recrystallisations, the compound had m. p. 71°

and was constant in rotatory power: (1) in ethyl alcohol ($c = 1{\cdot}959$, $l = 1$), $\alpha^{20°}_{5461} = +\ 4{\cdot}95°$, $[\alpha]^{20°}_{5461} = +\ 252{\cdot}7°$; (2) in carbon disulphide ($c = 2{\cdot}078$, $l = 1$), $\alpha^{20°}_{5461} = -\ 3{\cdot}79°$, $[\alpha]^{20°}_{5461} = -\ 182{\cdot}4°$, $\alpha^{20°}_{5791} = -\ 3{\cdot}23°$, $[\alpha]^{20°}_{5791} = -\ 155{\cdot}5°$. McKenzie and Ritchie (*loc. cit.*) give for (−)ethylbenzoin, m.p. 69—70°: $[\alpha]^{17°}_{5461} = -\ 250{\cdot}8°$ ($c = 2{\cdot}233$, $l = 1$) in ethyl alcohol, and $[\alpha]^{17°}_{5461} = +\ 180{\cdot}5°$ ($c = 2{\cdot}216$, $l = 1$) in carbon disulphide.

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221. *Solvent Effect in Dielectric Polarisation. Parts I and II.*

By George Thomson.

Part I. The Polarisations of Nitrobenzene and Chlorobenzene in Certain Ethers.

Since the publication (*Physikal. Z.*, 1933, **34**, 689; 1934, **35**, 346; *Trans. Faraday Soc.*, 1934, **30**, 729) of Müller's investigations of the influence of the dielectric constant of the solvent on the polarisation and apparent moment of solute molecules, much attention has been given to this phenomenon. Work has been, for the most part, directed towards the formulation of an expression which would make possible the calculation of the moment in the vapour state from measurements in one or more solvents. The present position is reviewed in detail by Glasstone (*Ann. Reports*, 1936, **33**, 117 *et seq.*). Empirical formulæ have been proposed by Müller (*loc. cit.*), Sugden (*Nature*, 1934, **133**, 413; *Trans. Faraday Soc.*, 1934, **30**, 720), and Jenkins (J., 1934, 480); theoretical relationships have been advanced by Weigle (*Helv. Physica Acta*, 1933, **6**, 68), Rau (*Proc. Indian Acad. Sci.*, 1935, *A*, **1**, 498), Le Fèvre (*Nature*, 1935, **136**, 181; J., 1935, 1747), Frank (*Proc. Roy. Soc.*, 1935, *A*, **152**, 171), and Higasi (*Sci. Papers Inst. Phys. Chem. Res. Tokyo*, 1936, **28**, 284). The equations derived by Rau and Le Fèvre are based on Raman and Krishnan's theory (*Proc. Roy. Soc.*, 1928, *A*, **117**, 589) of the relationship between the polarisation and the dielectric constant of a pure substance in the liquid state. Sugden's empirical equation bears a resemblance to the Raman and Krishnan equation, as was first pointed out by Goss (J., **1933**, **1341**; 1934, 696), but its validity from the standpoint of the experimental evidence was questioned by Jenkins and Sutton (J., 1935, 609), and more recently the assumptions involved in Raman and Krishnan's treatment of the subject have been adversely criticised by Mueller (*Physical Rev.*, 1936, **50**, 547) and Jenkins and Bauer (*J. Amer. Chem. Soc.*, 1936, **58**, 2435).

The present work was undertaken in order to test the applicability of some of these equations over a wider range of dielectric constant than is afforded by the non-polar solvents commonly used in such work, which have only a limited range varying from about 1·9 for hexane to about 2·7 for carbon disulphide (depending on the temperature at which the measurements are made). Polar solvents have higher dielectric constants and some have been used (for references see *Ann. Reports*, 1936, **33**, 133), but such solvents are not all suitable for this work, since in calculating the polarisation of the solute that of the solvent is assumed to be independent of its concentration. If this condition is not satisfied, estimation of the polarisation of the solute at infinite dilution, whether by graphical extrapolation or by calculation, seems of questionable validity. Higasi (*Sci. Papers Inst. Phys. Chem. Res. Tokyo*, 1934, **24**, 57) has used ethyl ether as a solvent: its polarisation in solution in benzene is remarkably constant except in very dilute solutions, in which there is a slight increase; its disadvantages are patent. In the present work the use of the higher aliphatic ethers has been investigated. The polarisations of di*iso*propyl, di-*n*-butyl, and diamyl ethers have been measured in benzene solutions. The values, although not quite constant, vary only very slightly in the range of concentrated solutions, the range corresponding to the dilute solution range when the ethers are used as solvents. The dielectric constants decrease as one goes up the series, and are of the orders 4·0, 3·1, and 2·8 re-

spectively, providing a useful extension to the range of solvents previously used in work of this kind. The polarisations of nitrobenzene and of chlorobenzene have been measured by using these ethers as solvents. The extrapolated values at infinite dilution are collected below.

Solvent.	Total polarisation. Nitrobenzene.	Chlorobenzene.
*iso*Propyl ether	293	68·8
n-Butyl ether	341	79·3
Amyl ether	350	81

Nitrobenzene, $P_E + P_A = 36·2$; chlorobenzene, $P_E + P_A = 34·9$ (Groves and Sugden, J., 1934, 1094).

Table I collates the values for $_{\infty}P_O$ derived from these measurements with the values found by Jenkins in various solvents and with the value for the vapour calculated from the results of Groves and Sugden (*loc. cit.*); it also includes a measurement of $_{\infty}P_O$ for nitrobenzene in carbon disulphide made in the course of the present work.

TABLE I.

Nitrobenzene at 25°.

Solvent.	$_{\infty}P_O$.	$\sqrt{_{\infty}P_O}$.	$\epsilon_{solv.}$.	$1/\epsilon$.	$(\epsilon - 1)^2$.
Hexane	336·3	18·34	1·8870	0·530	0·787
*cyclo*Hexane	323·8	17·99	2·0160	0·496	1·032
Decalin	316·7	17·80	2·1624	0·4625	1·350
Carbon tetrachloride	316·9	17·80	2·2277	0·4488	1·508
Benzene	317·6	17·82	2·2725	0·4399	1·620
Carbon disulphide *	286·4	16·92	2·6330	0·3798	2·666
Carbon disulphide †	273·8	16·55	2·6328	0·3798	2·664
Amyl ether	313·8	17·71	2·7980	0·3596	3·235
n-Butyl ether	304·8	17·46	3·0817	0·3249	4·335
*iso*Propyl ether	256·8	16·03	4·0370	0·2365	9·222
Chloroform	205·0	14·32	4·722	0·2118	13·85
(Vapour)	367·0	19·3	1·000	1·000	0

* Present work. † Jenkins.

The data of Table I are plotted in Fig. 1. If the values of $_{\infty}P_O$ are plotted against the dielectric constant of the solvent, a smooth curve can be drawn through the values in the ethers, in chloroform, in hexane, and for the vapour state. The values in carbon disulphide fall far below this curve, and the values found in the non-polar solvents benzene, *cyclo*hexane, decalin, and carbon tetrachloride fall about 10 c.c. below it. If, now, following Müller's empirical rule (*loc. cit.*)

$$P_O\text{, soln.} = P_O\text{, gas } [1 - \text{constant } (\epsilon - 1)^2]$$

we plot the values of P_O in solution against $(\epsilon - 1)^2$, a straight line is given by the points which formerly fell on the curve, and again the values in the same five solvents fall below the line, the values in carbon disulphide being very much below it. This straight line at $(\epsilon - 1)^2 = 0$ gives $P_O = 345$ c.c. The gas value calculated for 25° is 367 c.c. The values have also been plotted according to the rules of Jenkins (*loc. cit.*: $_{\infty}P_O$ against $1/\epsilon$) and Frank (*loc. cit.*: $\sqrt{_{\infty}P_O}$ against $1/\epsilon$). In each case the values in the non-polar solvents (except carbon disulphide) give an approximately linear graph which the values in the polar solvents carry into a smooth curve. The exceptional position of carbon disulphide must again be noted; it behaves, in fact, as though it had a very much higher dielectric constant. This appears to be its general behaviour with substances whose molecules have a radical on the dipole axis.

In each of these two graphs, extrapolation to $1/\epsilon = 1$ can have little real significance, since the highest value available for $1/\epsilon$ on the straight-line portion is only 0·530 and the lowest value about 0·36.

By using Higasi's formula (*loc. cit.*, 1936) calculations have been made of the moment of nitrobenzene in solutions in *iso*propyl, *n*-butyl, and amyl ethers. The equations are

$$\mu_{soln.} = \mu_{gas} + \Sigma\mu_i \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

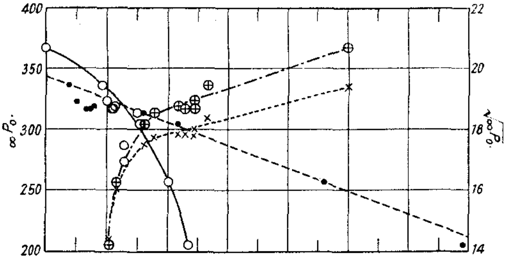
$$\Sigma\mu_i = 4\pi n\alpha\mu A \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where $4\pi n\alpha = 3(\epsilon - 1)/(\epsilon + 2)$ for the solvent, μ is the value of the moment of the solute in the vapour state, and A is given by the expression

$$A = -\frac{1}{K^2 - 1}\left\{1 - \frac{K}{\sqrt{K^2 - 1}} \log (K + \sqrt{K^2 - 1})\right\} - \tfrac{1}{3}$$

in which K is a parameter depending on the shape of the solute molecule and is evaluated from the Kerr constant.

FIG. 1.



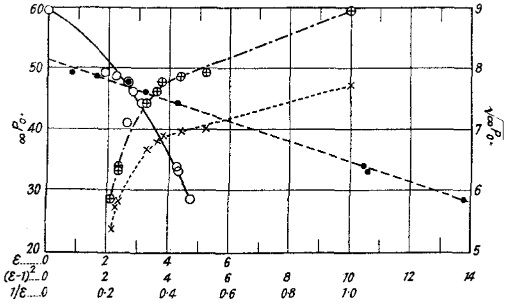
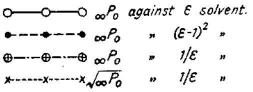


FIG. 2.



For nitrobenzene, $K = 1·69$, whence A is calculated to be $-0·128$, and the moment of nitrobenzene in the vapour state being taken as 4·23 (Groves and Sugden, *loc. cit.*), the following values are found :

Solvent.	$4\pi n\alpha$.	$\Sigma\mu_i$.	$\mu_{calc.}$.	$\mu_{obs.}$.
*iso*Propyl ether	1·509	−0·82	3·41	3·51
n-Butyl ether	1·229	−0·66	3·57	3·83
Amyl ether	1·125	−0·61	3·62	3·88

The values of P_0 found for chlorobenzene in these ethers and in carbon disulphide are compared in Table II with results obtained in various solvents at the same temperature by other workers. Fig. 2 expresses these data in graphical form.

TABLE II.

Chlorobenzene at 25°.

Solvent.	$_\infty P_O$.	$\sqrt{_\infty P_O}$.	$\epsilon_{solv.}$.	$1/\epsilon$.	$(\epsilon - 1)^2$.
Hexane [1]	49·1	7·007	1·904	0·525	0·817
Benzene [2]	48·7	6·98	2·273	0·440	1·620
Carbon disulphide [1]	47·6	6·90	2·633	0·380	2·664
Carbon disulphide	40·9	6·39	2·633	0·380	2·664
Amyl ether	46·1	6·79	2·798	0·360	3·235
Butyl ether	44·4	6·66	3·087	0·325	4·335
*iso*Propyl ether	33·9	5·82	4·232	0·236	10·45
Ethyl ether [3]	33·1	5·75	4·25	0·235	10·56
Chloroform [4]	28·7	5·36	4·722	0·212	13·85

[1] Williams and Ogg, *J. Amer. Chem. Soc.*, 1928, **50**, 94. [2] Smyth, Morgan, and Boyce, *ibid.*, p. 1536. [3] Higasi, *loc. cit.*, 1934. [4] Jenkins, *Trans. Faraday Soc.*, 1934 (Appendix).

If $_\infty P_O$ is plotted against ϵ for the solvent, a smooth curve is obtained from which no point deviates by more than 1·5 c.c. except the present author's value in carbon disulphide solution. Williams and Ogg's value appears to be too high, as does their value for nitrobenzene in carbon disulphide given in the same paper.

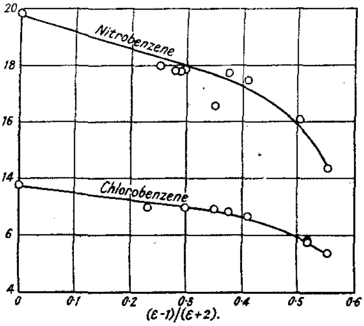
If $_\infty P_O$ is plotted against $(\epsilon - 1)^2$ (Müller's relationship), a very good straight line is obtained, no point deviating by more than 1·0 c.c., save the value in carbon disulphide. This straight line at $(\epsilon - 1)^2 = 0$ gives $P_O = 51{\cdot}4$, as compared with the value 59·5 for the vapour at 25° calculated from Groves and Sugden's data (*loc. cit.*). Graphed according to the rules of Jenkins and of Frank, the same types of curves are obtained as in the case of nitrobenzene.

Applying Higasi's equations and taking μ vap. $= 1{\cdot}69$ (Groves and Sugden, *loc. cit.*), we obtain the following values: $K = 1{\cdot}53$, whence $A = -0{\cdot}105$.

Solvent.	$4\pi n\alpha$.	$\Sigma\mu_i$.	$\mu_{calc.}$.	$\mu_{obs.}$.
*iso*Propyl ether	1·556	−0·276	1·41	1·28
n-Butyl ether	1·229	−0·218	1·47	1·46
Amyl ether	1·125	−0·199	1·49	1·56

It is evident from these collected data on both nitrobenzene and chlorobenzene that Jenkins's rule ($_\infty P_O$ linear with $1/\epsilon$) is unsound in that it certainly does not cover the case

FIG. 3.



of polar solvents as was originally claimed. Frank's rule ($\sqrt{_\infty P_O}$ linear with $1/\epsilon$) also fails to cover the case of polar solvents; further, both are unsatisfactory for non-polar

solvents in that estimation of the gas value from the solution values involves a most uncertain extrapolation.

Higasi's equation may be re-written

$$\mu_{soln} = \mu_{gas}(1 - 4\pi n\alpha A)$$

and since $4\pi n\alpha$ is proportional to $(\varepsilon - 1)/(\varepsilon + 2)$, we may represent it graphically by plotting ${}_{\infty}P_0$ against $(\varepsilon - 1)/(\varepsilon + 2)$. This gives a curve, not a straight line (cf. Fig. 3).

On the other hand, the linearity of ${}_{\infty}P_0$ with $(\varepsilon - 1)^2$ (Müller's relationship) is most striking, even though the deduced values of P_0 for the vapour are lower than the experimental values. Such low values from Müller's equation have already been noted by Cowley and Partington (J., 1936, 1184; this vol., p. 130).

EXPERIMENTAL.

Apparatus.—The resonance method was used, the oscillator being the dynatron circuit used by Sugden (J., 1933, 768). The measuring circuit differed from his in that, since no precision variable condenser was available, the arrangement of condensers described by Sayce and Briscoe (J., 1925, **127**, 315) was adopted. The small, single-plate, variable condenser was controlled by a brass worm engaging a fibre worm wheel attached to the condenser spindle. All the condensers were carefully shielded. The inductances of the measuring circuit were wound on formers built up of " Keramot " strips supported on special three-pin bases which plugged into the apparatus. Irregularities were at first experienced when ebonite was used as the insulating material in the measuring circuit, but the substitution of " Keramot," which has greatly superior surface properties, eliminated these satisfactorily. The dielectric cells were of the Sayce–Briscoe type.

Densities were measured in a quartz pyknometer. To test the accuracy of the apparatus, a series of measurements was made of the polarisation of nitrobenzene in benzene at 25°. This gave P_2 = 355 c.c., whereas Jenkins found 353·8 (*Nature*, 1934, **133**, 106). It is considered that the error in values of P_2 is not greater than 0·5%.

Materials.—Di*iso*propyl, di-*n*-butyl, and diamyl ethers were purchased. They were refluxed over sodium for several days, dried for 2 or 3 days over phosphoric oxide, and finally distilled from sodium through a long column in a current of dry nitrogen. It is difficult to ensure that these products are free from isomers : different specimens of the same ether were obtained with different physical constants, though test showed that peroxides were absent; *e.g.*, the amyl ether is probably a mixture of the active and the *iso*-ether. This variability does not affect the validity of work carried out with these solvents since we are concerned only with the effect of the dielectric constant of the solvent on the polarisation of the solute. The following physical constants are recorded: Di*iso*propyl ether, b. p. 67·2—67·4°/734·5 mm., $d_{4^\circ}^{25^\circ}$ 0·72002, ε_{25° 4·0370, $n_D^{25^\circ}$ 1·36658; a second specimen, b. p. 68·5—68·9°/770 mm., had $d_{4^\circ}^{25^\circ}$ 0·72185, ε_{25° 4·2321; di-*n*-butyl ether, b. p. 138·5—139·5°/754 mm., $d_{4^\circ}^{25^\circ}$ 0·76420, ε_{25° 3·0817, $n_D^{25^\circ}$ 1·39732; diamyl ether, b. p. 168—169°/755 mm., $d_{4^\circ}^{25^\circ}$ 0·77149, ε_{25° 2·7880, $n_D^{25^\circ}$ 1·40590, $\alpha_{5461}^{20^\circ}$ (2 dm.) 1·0°; a second specimen, b. p. 169—170°/770 mm., had $d_{4^\circ}^{25^\circ}$ 0·77165, ε_{25° 2·8220, $n_D^{25^\circ}$ 1·40646.

Benzene. Benzene for use in calibrating the dielectric cells was prepared from B.D.H. "extra pure" liquid by three fractional crystallisations, followed by drying over phosphoric oxide and distillation therefrom through a Widmer column. Its dielectric constant was assumed to be 2·2725 at 25°. The benzene used as a solvent in measuring the polarisations of the ethers was prepared from commercial " crystallisable " benzene by several hours' shaking with mercury, filtration, repeated shaking with concentrated sulphuric acid till no thiophen reaction was given, washing with sodium carbonate solution, then with water, and several days' drying over phosphoric oxide and distillation through a long column. The fraction, b. p. 80°, was collected. Its dielectric constant was lower than that of pure benzene and varied slightly from specimen to specimen, probably on account of the presence of aliphatic hydrocarbons.

Nitrobenzene. Nitrobenzene, prepared according to Masson (*Nature*, 1931, **128**, 726), had m. p. 5·65°.

Chlorobenzene. A commercial specimen was washed with dilute caustic soda solution, then with water, dried over calcium chloride and fractionated through a column; it had b. p. 131·4—131·6°/748 mm., $d_{4^\circ}^{25^\circ}$ 1·1016, $n_D^{25^\circ}$ 1·5222.

Carbon disulphide. Carbon disulphide " AnalaR " was shaken with mercury for several days, filtered, and fractionally distilled from iron turnings through a long column. The middle fraction, b. p. 45·9°/750 mm., was taken; it had $d_{4^\circ}^{25^\circ}$ 1·2566, ε_{25° 2·6330.

Results.—In the following tables the symbols have the usual significance.

iso*Propyl ether in benzene.*

f_2.	$d_{4°}^{25°}$.	$\epsilon_{25°}$.	P_2.
0·0000	0·87153	2·2680	—
0·04153	0·86253	2·3512	71·25
0·08560	0·85385	2·4390	71·10
0·12468	0·84615	2·5176	71·31
0·1255	0·84595	2·5185	71·22
0·17733	0·83504	2·6228	71·72
1·0000	0·72002	4·0370	71·34

n-*Butyl ether in benzene.*

f_2.	$d_{4°}^{25°}$.	$\epsilon_{25°}$.	P_2.
0·0000	0·87165	2·2705	—
0·014462	0·86777	2·2878	73·4
0·018621	0·86667	2·2928	73·5
0·025644	0·86483	2·3014	72·9
0·041543	0·86090	2·3206	72·1
0·046219	0·85970	2·3263	72·1
0·059866	0·85900	2·3418	71·4
0·12165	0·84684	2·4197	71·1
0·2900	0·82176	2·5962	70·6
0·57566	0·79199	2·8212	69·85
0·7364	0·78024	2·9315	69·76
1·0000	0·76420	3·0817	69·68

Amyl ether in benzene.

f_2.	$d_{4°}^{25°}$.	$\epsilon_{25°}$.	P_2.
0·0000	0·87154	2·2668	—
0·016642	0·86750	2·2845	77·4
0·026735	0·86515	2·2964	78·3
0·03434	0·86316	2·3049	78·6
0·051766	0·85953	2·3228	78·3
0·079138	0·85397	2·3512	78·4
0·13453	0·84363	2·4042	78·5
0·24410	0·82709	2·4902	78·10
0·41682	0·80762	2·5919	77·60
0·64046	0·79015	2·6957	77·4
0·73526	0·78447	2·7315	77·3
1·0000	0·77149	2·7980	76·83

Nitrobenzene in iso*propyl ether.*

0·0000	0·72002	4·0370	—
0·018657	0·72775	4·4375	278·6
0·033633	0·73388	4·7675	269·4
0·046452	0·73901	5·0430	259·3
0·066485	0·74741	5·4979	247·8
0·11592	0·76801	6·5633	218·8
0·167804	0·78929	7·670	196·3

$_{\infty}P_2 = 293.$

Nitrobenzene in n-*butyl ether.*

0·0000	0·76420	3·0817	—
0·00706	0·76645	3·1900	331·3
0·01274	0·76845	3·2773	326·5
0·017803	0·76990	3·3518	319·7
0·021237	0·77084	3·4040	317·3
0·032106	0·77397	3·5730	310·6

$_{\infty}P_2 = 341.$

Nitrobenzene in amyl ether.

0·0000	0·77149	2·7980	—
0·011968	0·77397	2·9368	338·7
0·01996	0·77610	3·0315	333·8
0·028604	0·77830	3·1329	324·4
0·03801	0·78048	3·2407	315·9
0·06145	0·78581	3·5280	300·7

$_{\infty}P_2 = 350.$

Chlorobenzene in iso*propyl ether.*

0·0000	0·72185	4·2321	—
0·01785	0·72755	4·2643	68·1
0·036527	0·73351	4·2948	67·2
0·051519	0·73820	4·3192	67·1
0·07037	0·74449	4·3517	66·7
0·084398	0·74880	4·3768	67·07
0·098722	0·75360	4·3995	66·66
0·17718	0·77882	4·5210	66·07

$_{\infty}P_2 = 68·8.$

Chlorobenzene in n-*butyl ether.*

0·0000	0·76420	3·0817	—
0·022484	0·76916	3·1265	77·0
0·04385	0·77400	3·1685	78·0
0·053446	0·77633	3·1880	77·7
0·081235	0·78242	3·2435	77·4
0·12493	0·79251	3·3301	76·2
0·17659	0·80481	3·4390	75·5

$_{\infty}P_2 = 79·3.$

Chlorobenzene in amyl ether.

0·0000	0·77149	2·7980	—
0·010784	0·77340	2·8157	80·5
0·021883	0·77565	2·8354	80·8
0·034236	0·77798	2·8559	80·0
0·048486	0·78066	2·8812	80·2
0·10081	0·79054	2·9700	78·5
0·17528	0·80480	3·0998	76·2
0·26470	0·82504	3·2822	74·9

$_{\infty}P_2 = 81.$

Nitrobenzene in carbon disulphide.

0·0000	1·2566	2·6330	—
0·004070	1·2560	2·7722	319·1
0·007494	1·2552	2·8862	310·6
0·008696	1·2550	2·9290	310·3
0·016248	1·2539	3·1869	298·4
0·024270	1·2529	3·4605	286·7
0·02522	1·2525	3·4990	286·8
0·037338	1·2512	3·9061	270·3

$_{\infty}P_2 = 322·6.$

Chlorobenzene in carbon disulphide.

0·0000	1·2566	2·6330	—
0·007829	1·2543	2·6692	75·4
0·014479	1·2523	2·6984	74·7
0·03060	1·2477	2·7694	74·1
0·048527	1·2424	2·8507	74·07
0·063287	1·2385	2·9176	73·78

$_{\infty}P_2 = 75·8.$

Part II. Note on Positive Solvent Effect of Butyl and Amyl Ethers.

It is now generally recognised that, although most substances show a lower polarisation in solution than in the gaseous state, yet there exist some which exhibit an opposite behaviour. These phenomena have been related to the Kerr constant by Higasi (*Bull. Inst. Phys. Chem. Res. Tokyo*, 1935, *A*, 152, 171; *loc. cit.*, 1936) and Rau (*loc. cit.*). It is predicted that, according as the substance has a positive or a negative value of the Kerr constant, the moment in solution will be respectively lower or higher than that in the gaseous state (" negative " or " positive " solvent effect). Similar conclusions regarding the relation between the sign of Kerr constant and that of the solvent effect are reached by Le Fèvre (*locc. cit.*).

Ethers have negative values of Kerr constant, and for ethyl ether a " positive " solvent effect has been observed (Higasi, *loc. cit.*). For butyl and amyl ethers no measurements of the polarisation in the gaseous state are available. If, however, these substances exhibit a " positive " solvent effect the polarisation in solution should decrease as the dielectric constant of the solvent decreases. It is found that for each ether the polarisation in

hexane is lower than in benzene at the same temperature and also lower than that of the liquid ether. The values are:

	Pure ether.	In benzene.	In hexane.
	P.	P_2.	P_2.
n-Butyl ether	69·68	74·5	68·6
Amyl ether	77·45	78·6	74·5

The effect observed is smaller for amyl than for butyl ether. This is probably to be expected, since the recorded Kerr constants of the ethers as vapours decrease in the order dimethyl > diethyl > di-*n*-propyl. No data are available for the Kerr constants of butyl and amyl ethers.

The hexane used was *n*-hexane "free from aromatic hydrocarbons" freshly distilled from phosphoric oxide; b. p. 68·7—68·9°/745 mm., $d_{4°}^{25°}$ 0·66662, $\epsilon_{25°}$ 1·8863.

The measurements are as follows:

Butyl ether in n-*hexane.*

f_2.	$d_{4°}^{25°}$.	$\epsilon_{25°}$.	P_2.
0·0000	0·66662	1·8863	—
0·020544	0·66916	1·9102	68·8
0·04440	0·67267	1·9390	68·82
0·10019	0·67939	2·0063	69·41
0·19716	0·69082	2·1215	69·32
0·38624	0·71163	2·3480	69·44
0·63757	0·73559	2·6528	69·65
0·84250	0·75290	2·8946	69·61
1·0000	0·76420	3·0817	69·68

$_{\infty}P_2$ = 68·6.

Amyl ether in n-*hexane.*

f_2.	$d_{4°}^{25°}$.	$\epsilon_{25°}$.	P_2.
0·0000	0·66662	1·8863	—
0·01989	0·66975	1·9076	74·7
0·038187	0·67271	1·9273	74·77
0·065344	0·67736	1·9582	75·34
0·091623	0·68148	1·9855	75·10
0·18150	0·69478	2·0863	76·25
0·32879	0·71300	2·2439	77·15
0·68072	0·74805	2·5698	77·37
0·79597	0·75733	2·6619	77·29
1·0000	0·77165	2·8220	77·45

$_{\infty}P_2$ = 74·5.

Summary.

The polarisations of nitrobenzene and chlorobenzene in *iso*propyl, *n*-butyl, and amyl ethers are found to be consistent with the results obtained in other solvents, including chloroform.

The linear relationships proposed by Jenkins, Frank, and Higasi are found to be invalid for polar solvents.

The empirical relationship proposed by Müller is found to give a linear graph for polar and non-polar solvents, though extrapolation gives a value for the gaseous state which is too low.

Measurements of the polarisations of butyl and amyl ethers in benzene and in hexane show a decrease in polarisation with decreasing dielectric constant of solvent as has been predicted for substances with negative values of Kerr constant.

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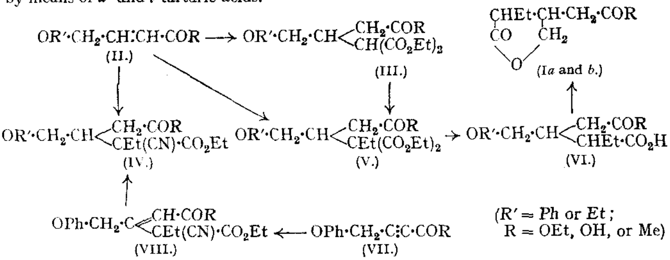
222. *The Jaborandi Alkaloids. Part I. The Synthesis of Homo- and* iso*Homo-pilopic Acids and of* r-*Pilocarpidine and* r-iso*Pilocarpidine by New Methods and the Resolution of* r-*Pilocarpine.*

By A. N. Dey.

Starting with ethyl ethylsuccinate and ethyl formate, Tschitschibabin and Preobrashenski (*Ber.*, **1930**, **63**, 460) synthesised *r*-pilopic (β-ethylparaconic) and *r*-*iso*pilopic acids; they also showed that *d*-*iso*pilopic acid is identical with the *iso*pilopic acid obtained by Jowett (J., 1901, **79**, 1331) by the oxidation of *iso*pilocarpine (see also Pinner and Kohlhammer, *Ber.*, 1900, **33**, 2357; 1901, **34**, 730; Langenbeck, *Ber.*, 1924, **57**, 2072). From these two acids, Preobrashenski, Poljakowa, and Preobrashenski (*Ber.*, 1934, **67**, 710; 1935, **68**, 844, 850) synthesised the homologues, *r*-homopilopic and *r*-*iso*homopilopic acids. They also pre-

pared *d*-homopilopic acid by another method and showed that it is identical with the homopilopic acid produced by the oxidation of pilocarpine (Jowett, *loc. cit.*). Since Preobrashenski and Preobrashenski (*Ber.*, **1933**, **66**, 1187, 1536) had already converted homopilopic and *iso*homopilopic acids, obtained by the oxidation of pilocarpine and *iso*pilocarpine respectively, into *d*-pilocarpidine and *d*-*iso*pilocarpidine, and thence by methylation into *d*-pilocarpine and *d*-*iso*pilocarpine, the synthesis of the four bases has been fully achieved.

The present paper describes the synthesis of *r*-homo- and *r*-*iso*homo-pilopic acids and of *r*-pilocarpidine and *r*-*iso*pilocarpidine by new methods and the resolution of *r*-pilocarpine by means of *d*- and *l*-tartaric acids.



(R′ = Ph or Et; R = OEt, OH, or Me)

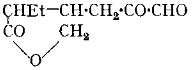
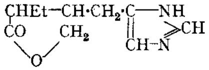
Synthesis of r-*Homo- and* r-iso*Homo-pilopic Acids.*—Elimination of hydrogen bromide from the easily available *ethyl α-bromo-γ-phenoxybutyrate* gave a poor yield of *ethyl γ-phenoxycrotonate* (II; R = OH, R′ = Ph). Therefore this ester was prepared from the corresponding *acid*, obtained in a yield of 60% by condensing phenoxyacetaldehyde with malonic acid. On condensation with ethyl cyanoacetate and ethyl iodide, the unsaturated ester gave *ethyl α-cyano-β-phenoxymethyl-α-ethylglutarate* (IV; R = OEt, R′ = Ph), which on hydrolysis furnished the cis- and trans-*glutaric acids* (VI; R = OH, R′ = Ph); these were separated by means of acetyl chloride. On hydrolysis with hydrobromic acid the *cis*- and the *trans*-acid gave *r*-homopilopic and *r*-*iso*homopilopic acid (I*a* and *b*, R = OH) respectively. The glutaric acids (VI) were obtained in better yield from the *carbethoxyglutaric* ester (V; R = OEt, R′ = Ph), prepared from *ethyl β-chloro-γ-phenoxybutyrate* or its *nitrile* and ethyl malonate and ethyl iodide. The hydrolysis of the phenoxy-group of the phenoxyglutaric acids, however, did not proceed smoothly and usually a poor yield of the final lactonic acids resulted. A higher temperature was more effective, but led to isomerisation of the lactonic acids. The corresponding cis- and trans-*ethoxyglutaric acids* (VI; R = OH, R′ = Et) were therefore prepared from ethyl γ-ethoxycrotonate (II; R = OEt, R′ = Et); they were separated by means of acetyl chloride as well as by the difference in solubility of their copper salts. The ethoxy-group was easily hydrolysed by hydrobromic acid and *r*-homopilopic and *r*-*iso*homopilopic acids were obtained in yields of 60%.

With excess of *p*-toluidine, *r*-homopilopic acid formed a *di*-p-*toluidide* difficultly soluble in methyl alcohol, whereas *r*-*iso*homopilopic acid gave only a more easily soluble *mono*-p-*toluidide*. This property was utilised to identify the two acids in their mixtures. When heated with concentrated hydrochloric acid at 200°, *r*-homopilopic acid was converted to the extent of 60% into the isomeride, but *r*-*iso*homopilopic acid remained unaffected. In presence of sodium ethoxide the ester of either acid underwent isomerisation. On distillation under atmospheric pressure *r*-homopilopic acid was quantitatively transformed into its isomeride.

Synthesis of r-*Pilocarpidine and* r-iso*Pilocarpidine.*—With methylzinc iodide, *r*-homopilopoyl chloride formed *β-acetonyl-α-ethyl-γ-butyrolactone* (I*a*, R = Me), and *r*-*iso*homopilopoyl chloride gave the isomeric *ketone* (I*b*). The constitutions of the two ketones were established by synthesis: *β-ethoxyethylideneacetone* (II; R = Me, R′ = Et), prepared either

by condensing ethoxyacetaldehyde with acetone in presence of sodium hydroxide or from γ-ethoxycrotonyl chloride and methylzinc iodide, gave, on condensation with ethyl cyanoacetate and ethyl iodide, *ethyl α-cyano-γ-acetyl-β-ethoxymethyl-α-ethylbutyrate* (IV; R = Me, R′ = Et), which on hydrolysis with fuming hydrobromic acid yielded (I*a*) and (I*b*). The same ketones were also obtained from ethyl α-cyano-γ-acetyl-β-phenoxymethyl-α-ethylbutyrate (IV; R = Me, R′ = Ph), prepared by hydrogenating the condensation product (VIII; R = Me, R′ = Ph) of *phenoxypropynyl methyl ketone* (VII, R = Me) with ethyl cyanoacetate and ethyl iodide. The acetylenic ketone itself was prepared by condensing acetyl chloride with the sodio-salt of phenyl propargyl ether.

On condensation with benzaldehyde in presence of dilute sodium hydroxide solution, the ketone (I*b*, R = Me) formed a solid *benzylidene* derivative (I*b*, R = CH:CHPh), whereas the ketone (I*a*) formed an isomeric liquid *benzylidene* derivative (I*a*, R = CH:CHPh) together with the solid isomeride. The production of the latter was due to the isomerising action of the alkali and could not be prevented. However, the acetylenic ketone produced by the condensation of *r*-homopilopoyl chloride and the sodio-derivative of phenylacetylene gave, on partial hydrogenation (Paal and Hartmann, *Ber.*, 1909, **42**, 3930), the liquid benzylidene derivative uncontaminated with the solid isomeride.

(IX*a* and *b*.)   (X*a* and *b*.)

On decomposition of their ozonides the benzylidene derivatives (I*a* and *b*, R = CH:CHPh) gave the *glyoxal* derivatives (IX*a* and *b*) respectively, which with ammonia and formaldehyde formed *r*-pilocarpidine and *r*-*iso*pilocarpidine respectively. These bases could not be resolved, but on methylation they gave *r*-pilocarpine and *r*-*iso*pilocarpine, respectively, of which the former was easily separated into its optical components by means of *d*- and *l*-tartaric acids, the *l*-acid forming an insoluble salt with the *d*-form of the base. The *d*-base thus prepared was identified with natural pilocarpine through the mixed melting points of their nitrates and hydrogen tartrates. The *l*-base, like pilocarpine, underwent isomerisation in presence of alkali, forming *l*-*iso*pilocarpine, which, when combined with an equal amount of *iso*pilocarpine, formed an inactive base identical with the *r*-*iso*pilocarpine described above.

Experimental.

Ethyl α-Bromo-γ-phenoxybutyrate.—α-Bromo-γ-phenoxybutyric acid was prepared, essentially by Fischer and Blumenthal's method (*Ber.*, 1907, **40**, 106), from β-phenoxyethylmalonic acid (Haworth and Perkin, J., 1896, **69**, 165; see also Leuchs, *Ber.*, 1911, **44**, 1507). The *ethyl* ester, b. p. 199—200°/16 mm., was prepared by the usual method (Found: Br, 27·6. $C_{12}H_{15}O_3Br$ requires Br, 27·9%).

Bromoacetal (cf. Späth, *Monatsh.*, 1915, **35**, 4).—Bromine (630 g.) was added with stirring to paraldehyde (200 g.) as fast as the reaction proceeded, the temperature being kept at 10—13°. The mixture was poured into alcohol (800 c.c.) and after 48 hours the whole was poured into a saturated solution of sodium carbonate. The oily bromoacetal (400 g.) was separated, washed, dried, and distilled, giving the pure acetal (300—350 g.), b. p. 65—68°/12 mm.

Phenoxyacetaldehyde.—Shrœtter's method (*Ber.*, 1885, **13**, 2315) gave a poor yield, so the following one was used. Bromoacetal (197 g.) and an alcoholic solution of sodium phenoxide (prepared from 94 g. of phenol, 23 g. of sodium, and 190 c.c. of alcohol) were heated (150—160°) in an autoclave for 4 hours, the solvent removed by distillation in a vacuum, the residue poured into water, and the oily product separated with ether. The residue from the ethereal solution, on distillation, gave the phenoxyacetal (150 g.), b. p. 132—134°/10 mm., which was hydrolysed with dilute sulphuric acid, and the phenoxyacetaldehyde (88 g.) formed separated with ether. It boiled at 105°/10 mm.

γ-Phenoxycrotonic Acid (II; R = OH, R′ = Ph).—A mixture of ethyl α-bromo-γ-phenoxybutyrate (50 g.) and freshly distilled diethylaniline (150 g.) was heated (170—180°) for 12 hours and poured into dilute hydrochloric acid; the product on fractional distillation gave *ethyl γ-phenoxycrotonate*, b. p. 182—184°/12 mm., in 20% yield (Found: C, 69·8; H, 6·6. $C_{12}H_{14}O_3$ requires C, 69·9; H, 6·9%).

On hydrolysis with alcoholic potassium hydroxide, and acidification of the resulting potassium salt with dilute hydrochloric acid, *γ-phenoxycrotonic acid* was obtained. It crystallised from dilute alcohol in needles, m. p. 138°, insoluble in water and difficultly soluble in benzene (Found: C, 67·2; H, 5·3. $C_{10}H_{10}O_3$ requires C, 67·4; H, 5·6%). The same acid was obtained in better yield by heating phenoxyacetaldehyde (136 g.), malonic acid (104 g.), and pyridine (120 g.) together on a water-bath for 1 hour, pouring the mixture into dilute hydrochloric acid, and extracting the acid with ether.

Ethyl α-Cyano-β-phenoxymethyl-α-ethylglutarate (IV; R = OEt, R′ = Ph).—A mixture of ethyl γ-phenoxycrotonate (II; R = OEt, R′ = Ph) and ethyl cyanoacetate (12 g.) was refluxed for 24 hours with a solution of sodium ethoxide (from 2·3 g. of sodium) in alcohol (30 c.c.), ethyl iodide (20 g.) then added, and the mixture refluxed until it became neutral. The *cyano*-ester, b. p. 221°/8 mm., was separated in the usual way in a yield of 66% (Found: C, 65·3; H, 7·1. $C_{19}H_{25}O_5N$ requires C, 65·7; H, 7·2%). On hydrolysis with an excess of alcoholic potassium hydroxide the ester gave *α-cyano-β-phenoxymethyl-α-ethylglutaric acid*, which crystallised from dilute alcohol in small needles, m. p. 194°, insoluble in benzene and water, but soluble in ether, acetone, and methyl alcohol (Found: C, 61·6; H, 5·7. $C_{15}H_{17}O_5N$ requires C, 61·9; H, 5·8%).

β-Phenoxymethyl-α-ethylglutarimide.—The above cyano-acid (10 g.) was refluxed for ½ hour with concentrated hydrochloric acid (50 g.), and the solution cooled and extracted with ether. The extract was washed with dilute sodium carbonate solution (alkaline washing *A*), dried, and distilled, the *imide* (34 g.) being obtained as a thick oil, b. p. 245°/12 mm. (Found: C, 68·0; H, 6·6; N, 5·7. $C_{14}H_{17}O_3N$ requires C, 68·0; H, 6·9; N, 5·7%).

cis- *and* trans-*β-Phenoxymethyl-α-ethylglutaric Acids* (VI; R = OH, R′ = Ph).—The cis-*acid* was obtained as an oil on hydrolysis of the above imide with concentrated hydrochloric acid (Found: C, 62·9; H, 6·5. $C_{14}H_{18}O_5$ requires C, 67·7; H, 6·5%). By acetyl chloride or acetic anhydride in the cold it was converted into the *anhydride*, b. p. 222—224°/18 mm. (Found: C, 67·6; H, 6·4. $C_{14}H_{16}O_4$ requires C, 67·7; H, 6·5%). The *p*-toluidic acid could not be obtained as a solid product, but the p-*tolylimide* was prepared by heating equimolecular quantities of the anhydride and *p*-toluidine at 150° for 1 hour; it crystallised from dilute alcohol in long needles, m. p. 215° (Found: C, 74·4; H, 6·6. $C_{21}H_{23}O_3N$ requires C, 74·8; H, 6·8; N, 4·2%).

When the alkaline washing (*A*) was acidified, the trans-*acid*, mixed with a little of the *cis*-acid, separated as an oil. This was removed in ether and mixed with an equal volume of acetyl chloride; after ½ hour the excess of acetyl chloride was removed over sodium hydroxide in a vacuum at the ordinary temperature, the residue dissolved in ether, and the solution washed with dilute aqueous sodium bicarbonate. Acidification of this washing gave the pure *trans*-acid as an oil (Found: C, 63·2; H, 6·7%). It was quantitatively transformed into the anhydride of the *cis*-acid by boiling acetic anhydride or acetyl chloride.

r-*Homopilopic Acid* (Ia, R = OH).—A mixture of the *cis*-glutaric acid (VI; R = OH, R′ = Ph) (10 g.) and fuming hydrobromic acid (50 g.) was refluxed for 6 hours, the solution evaporated to dryness under reduced pressure, and the residual mixture of acids esterified by refluxing with alcohol (100 c.c.) saturated with hydrogen chloride. On fractional distillation of the esters, ethyl *r*-homopilopate, b. p. 181°/17 mm., was obtained in 20% yield (Found: C, 59·8; H, 8·0. Calc. for $C_{10}H_{16}O_4$: C, 60·0; H, 8·0%). The other product was mostly the ester of the unchanged glutaric acid. On hydrolysis of the ethyl ester with concentrated hydrochloric acid, *r*-homopilopic acid was obtained as a thick oil, b. p. 199°/1·5 mm. It was obtained crystalline, m. p. 99—100°, by solution in the minimum quantity of ether and precipitation with light petroleum (Preobrashenski gives m. p. 101°) (Found: C, 55·6; H, 6·8; equiv., 172. Calc. for $C_8H_{12}O_4$: C, 55·8; H, 7·0%; equiv., 173). The *di*-p-*toluidide*, prepared by heating the acid chloride (1 mol.) with *p*-toluidine (2 mols.) at 150° for 2 hours, was sparingly soluble in cold methyl alcohol and was crystallised from dilute alcohol; m. p. 225° (Found: C, 75·2; H, 7·0. $C_{22}H_{26}O_2N_2$ requires C, 75·4; H, 7·4%).

r-iso*Homopilopic Acid* (Ib, R = OH).—Hydrolysis of the *trans*-acid (VI; R = OH, R′ = Ph) in a similar manner gave *r*-*iso*homopilopic acid, which separated as a crystalline solid from a warm aqueous solution on passage of hydrogen chloride; m. p. 75° (Found: C, 55·5; H, 6·7%; equiv., 173). The ethyl ester boiled at 171°/17 mm. (Found: C, 59·9; H, 8·0%). The *mono*-p-*toluidide* was very soluble in methyl alcohol, but less soluble in ethyl alcohol; it separated from dilute alcohol in needles, m. p. 115° (Found: C, 68·8; H, 7·0; N, 5·6. $C_{15}H_{19}O_3N$ requires C, 69·0; H, 7·3; N, 5·4%).

The p-*Toluidides of* d-*Homopilopic and* d-iso*Homopilopic Acids*.—(i) *d*-Homopilopic acid, prepared from its methylamide derivative obtained by the ozonisation of pilocarpine, formed

a *di*-p-*toluidide*, m. p. 268° after crystallisation from alcohol (Found : C, 75·1; H, 7·2; N, 8·1. $C_{22}H_{26}O_2N_2$ requires C, 75·4; H, 7·4; N, 8·0%).

(ii) The *mono*-p-*toluidide* of *d*-*iso*homopilopic acid (obtained from the ozonisation product of *iso*pilocarpine) crystallised from dilute alcohol in needles, m. p. 142° (Found : C, 68·7; H, 7·2; N, 5·5. $C_{15}H_{19}O_3N$ requires C, 69·0; H, 7·3; N, 5·4%).

Isomerisation of Ethyl r-*Homopilopate*.—The ester (10 g.) was mixed with alcoholic sodium ethoxide (1 g. of sodium in 50 c.c. of alcohol) and left at the ordinary temperature for 72 hours. The solution was then exactly neutralised with alcoholic hydrogen chloride, the solvent removed under reduced pressure, and the residual ester hydrolysed with concentrated hydrochloric acid. The acid obtained was converted by thionyl chloride into the acid chloride, which was heated at 150° with an excess of *p*-toluidine. The mixture of *p*-toluidide derivatives was separated in the ordinary way and on fractional crystallisation gave two solids identical with the toluidide derivatives of *r*-homo- and *r*-*iso*homo-pilopic acids described above. The conversion of ethyl *r*-homopilopate into its isomeride as calculated from the proportion of the toluidides formed was 40%.

Ethyl *r*-*iso*homopilopate under similar conditions formed a similar mixture.

Isomerisation of r-*Homopilopic Acid*.—A mixture of the acid (10 g.) and concentrated hydrochloric acid (30 c.c.) was heated in a sealed tube for 4 hours at 200°, the solution evaporated to dryness, the residue dissolved in a dilute solution of sodium carbonate, and the alkaline solution extracted with ether to remove the neutral products. The acids reprecipitated from the alkaline solution by acidification were converted into the *p*-toluidide derivatives, which on fractional crystallisation were separated into two toluidides identical with those prepared from *r*-homo- and *r*-*iso*homo-pilopic acids. The conversion in this case was 60%.

β-*Hydroxy*-γ-*phenoxybutyronitrile*.—A solution of α-monochlorohydrin γ-phenyl ether (100 g.) in methyl alcohol (200 c.c.) was boiled under reflux (½ hour) while a solution of potassium cyanide (40 g.) in water (80 c.c.) was gradually added. After being refluxed for another hour, the solvent was distilled off, and the residue mixed with alcohol–ether (1 : 1). On removal of the solvents from the filtered solution, the *nitrile* (73 g.) was obtained as a thick oil, b. p. 201—205°/15 mm. It solidified to a felted mass, m. p. 59°, soluble in alcohol, acetone, benzene, ether, and ethyl acetate, but insoluble in light petroleum and water. For analysis it was purified by solution in the minimum quantity of ether and reprecipitation with light petroleum (Found : C, 67·5; H, 6·1. $C_{10}H_{11}O_2N$ requires C, 67·8; H, 6·2%).

(1) The nitrile (100 g.) was refluxed with alcohol (180 c.c.) and sulphuric acid (40 c.c.) for 6 hours, and *ethyl* β-*hydroxy*-γ-*phenoxybutyrate*, b. p. 189°/15 mm., obtained in a yield of 65% (Found : C, 64·2; H, 7·0. $C_{12}H_{16}O_4$ requires C, 64·3; H, 7·1%).

(2) By the interaction of the nitrile (17 g.) and phosphorus pentachloride (20 g.), β-*chloro*-γ-*phenoxybutyronitrile*, b. p. 175—177°/13 mm., was formed in a yield of 59% (Found : Cl, 18·0. $C_{10}H_{10}ONCl$ requires Cl, 18·2%).

Ethyl β-*chloro*-γ-*phenoxybutyrate*, obtained in 60% yield from ethyl β-hydroxy-γ-phenoxybutyrate and phosphorus pentachloride, boiled at 165—166°/10 mm. (Found : C, 59·2; H, 6·1. $C_{12}H_{15}O_3Cl$ requires C, 59·4; H, 6·2%).

Ethyl α-*carbethoxy*-β-*phenoxymethylglutarate* (III; R = OEt, R′ = Ph), obtained in a yield of 60% by condensing the preceding ester with ethyl sodiomalonate in the ordinary way, boiled at 239—240°/12 mm. (Found : C, 62·0; H, 6·9. $C_{19}H_{26}O_7$ requires C, 62·3; H, 7·1%). On ethylation through the sodio-derivative it gave *ethyl* α-*carbethoxy*-β-*phenoxymethyl*-α-*ethylglutarate* (V; R = OEt, R′ = Ph), b. p. 229—230°/11 mm., in 65% yield (Found : C, 63·8; H, 7·4. $C_{21}H_{30}O_7$ requires C, 64·0; H, 7·6%). Hydrolysis of the latter ester with concentrated hydrochloric acid gave a mixture of the *cis*- and *trans*-glutaric acids (VI; R = OH, R′ = Ph).

Ethyl α-*carbethoxy*-γ-*cyano*-β-*phenoxymethylbutyrate*, prepared in 60% yield from β-chloro-γ-phenoxybutyronitrile and ethyl sodiomalonate, boiled at 246°/10 mm. (Found : C, 63·8; H, 6·4. $C_{17}H_{21}O_5N$ requires C, 64·0; H, 6·6%). On ethylation through its sodio-derivative it gave a 65% yield of *ethyl* α-*carbethoxy*-γ-*cyano*-β-*phenoxymethyl*-α-*ethylbutyrate*, b. p. 240—242°/11 mm. (Found : C, 65·4; H, 7·1. $C_{19}H_{25}O_5N$ requires C, 65·7; H, 7·2%), which on hydrolysis furnished a mixture of the two glutaric acids (VI; R = OH, R′ = Ph).

β-*Hydroxy*-γ-*ethoxybutyronitrile*.—As Lespieau's process (*Bull. Soc. chim.*, 1905, **33**, 469) proved unsatisfactory for the preparation of large quantities, the nitrile was obtained by running α-monochlorohydrin γ-ethyl ether (140 g.) (Fourneau and Ribas, *ibid.*, 1926, **39**, 1584) slowly with vigorous stirring into a concentrated solution of potassium cyanide (70 g. in 70 c.c. of water) at 50—60°. The temperature, which had at first to be controlled by cooling, was finally raised to 70°, and the mixture stirred for 5 hours. It was then cooled, potassium chloride removed,

and the filtrate distilled fractionally, the nitrile, b. p. 137°/10 mm., being obtained in a yield of 65%.

Ethyl α-cyano-β-ethoxymethyl-α-ethylglutarate (IV; R = OEt, R' = Et), obtained by the condensation of ethyl γ-ethoxycrotonate with ethyl cyanoacetate and ethyl iodide (see the corresponding phenoxy-derivative; p. 1060), had b. p. 200—204°/12 mm. (65% yield) (Found: C, 60·0; H, 8·3. $C_{15}H_{25}O_5N$ requires C, 60·2; H, 8·4%).

Ethyl α-carbethoxy-β-ethoxymethyl-α-ethylglutarate (V; R = OEt, R' = Et), prepared by condensing ethyl γ-ethoxycrotonate with ethyl malonate and ethyl iodide in the ordinary way, had b. p. 184—185°/15 mm. (yield, 60%) (Found: C, 58·9; H, 8·5. $C_{17}H_{30}O_7$ requires C, 59·0; H, 8·7%). The intermediate ester, *ethyl α-carbethoxy-β-ethoxymethylglutarate* (III; R = OEt, R' = Et), b. p. 190—192°/13 mm., was also isolated (Found: C, 56·3; H, 8·0. $C_{15}H_{26}O_7$ requires C, 56·6; H, 8·2%); on hydrolysis with concentrated hydrobromic acid it gave *norhomopilopic acid*, b. p. 204—206°/12 mm. (Found: C, 49·7; H, 5·4. $C_6H_8O_4$ requires C, 50·0; H, 5·6%).

Ethyl α-carbethoxy-γ-cyano-β-ethoxymethyl-α-ethylbutyrate, obtained in 60% yield by condensing γ-ethoxybutyronitrile with ethyl malonate and ethyl iodide, boiled at 192—194°/14 mm. (Found: C, 60·0; H, 8·2. $C_{15}H_{25}O_5N$ requires C, 60·2; H, 8·4%). The intermediate *ethyl α-carbethoxy-γ-cyano-β-ethoxymethylbutyrate*, b. p. 194—195°/18 mm., was isolated (Found: C, 57·3; H, 7·4. $C_{13}H_{21}O_5N$ requires C, 57·6; H, 7·7%); on hydrolysis with hydrobromic acid it also gave norhomopilopic acid.

β-Ethoxymethyl-α-ethylglutaric Acids (VI; R = OH, R' = Et).—The esters (IV; R = OEt, R' = Et) and (V; R = Et, R' = Et) on hydrolysis with caustic potash (40% solution) gave the corresponding carboxyglutaric acid, which on decarboxylation furnished a mixture of the *cis*- and *trans*-glutaric acids (VI; R = OH, R' = Et). These were dissolved in water and neutralised with ammonia, and dilute copper sulphate solution added till the precipitation of the copper salt was maximal. The filtered solution was acidified, and the cis-*acid* extracted with ether. Decomposition of the precipitated copper salt with hydrogen sulphide gave the *trans*-acid.

The *cis*-acid, recrystallised from hexane, melted at 78° (Found: C, 54·9; H, 8·1. $C_{10}H_{18}O_5$ requires C, 55·0; H, 8·2%). When treated with cold acetyl chloride or boiled with acetic anhydride, it formed the *anhydride*, b. p. 185°/16 mm. (Found: C, 59·8; H, 7·8. $C_{10}H_{16}O_4$ requires C, 60·0; H, 8·0%). The *p*-toluidic acid obtained from this anhydride and *p*-toluidine was a liquid, which, after being heated for ½ hour at 200°, formed the p-*tolylimide*, m. p. 205° (from alcohol) (Found: C, 70·3; H, 7·8; N, 4·9. $C_{17}H_{23}O_3N$ requires C, 70·6; H, 8·0; N, 4·8%).

The *trans*-acid could not be obtained solid. It was unaffected by cold acetyl chloride, but when boiled with this reagent or with acetic anhydride it was quantitatively transformed into the anhydride of the *cis*-acid.

β-Acetonyl-α-ethyl-γ-butyrolactone (I*a*, R = Me).—A benzene solution of the acid chloride prepared from *r*-homopilopic acid (50 g.) and thionyl chloride (250 c.c.) was added slowly to a solution prepared from methyl iodide (35 c.c.), zinc–copper couple (65 g.), benzene (20 c.c.), and ethyl acetate (10 c.c.), cooled in a freezing mixture. The mixture was left in ice for 2 hours, then decomposed with ice and dilute sulphuric acid, the oily layer separated with ether, washed and dried, and the solvent removed. The residual oil on distillation gave the above *ketone*, b. p. 194—205°/12 mm., mainly at 202—205°/12 mm. (yield, 21%) (Found: C, 63·4; H, 8·1. $C_9H_{14}O_3$ requires C, 63·6; H, 8·2%). The *semicarbazone* crystallised from dilute alcohol in small needles, m. p. 184° (Found: C, 52·6; H, 7·2; N, 18·3. $C_{10}H_{17}O_3N_3$ requires C, 52·9; H, 7·5; N, 18·5%).

iso-*β-Acetonyl-α-ethyl-γ-butyrolactone* (I*b*, R = Me), obtained in 30% yield from *r-iso*homopilopic acid in a similar way, had b. p. 186—188°/13 mm. (Found: C, 63·4; H, 8·0%). The *semicarbazone* crystallised from dilute alcohol in thick needles, m. p. 164° (Found: C, 52·5; H, 7·3; N, 18·6%).

Synthesis of the Ketones (I*a* and *b*, R = Me).—(1) Ethoxyacetal (30 g.) was hydrolysed by boiling (30 mins.) with water and one drop of concentrated sulphuric acid, the solution mixed with acetone (30 c.c.), and sodium hydroxide (4 g. in 6 c.c. of water) stirred in during an hour. After being stirred for 48 hours, the mixture was extracted with ether, the extract washed with a concentrated solution of potassium chloride, and the ether removed. The residual *β-ethoxyethylideneacetone* (II; R = Me, R' = Et), b. p. 61°/11 mm., polymerised after a few days (Found: C, 65·3; H, 9·0. $C_7H_{12}O_2$ requires C, 65·6; H, 9·3%). The *semicarbazone* had m. p. 135° after crystallisation from dilute alcohol (Found: C, 62·2; H, 5·4; N, 18·0. $C_8H_{15}O_2N_3$ requires C, 62·3; H, 5·6; N, 18·2%).

A mixture of the above ketone (12·8 g.) and the alcoholic solution prepared from 2·3 g. of sodium, 30 c.c. of alcohol, and 12 g. of ethyl cyanoacetate was refluxed for 12 hours, ethyl iodide (15 c.c.) then added, and refluxing continued till the liquid became neutral. The product, on being worked up, gave *ethyl α-cyano-γ-acetyl-β-ethoxymethyl-α-ethylbutyrate* (IV; R = Me, R′ = Et), b. p. 187—193°/17 mm., in a yield of 30% (Found: C, 62·1; H, 8·2. $C_{14}H_{23}O_4N$ requires C, 62·4; H, 8·5%). On hydrolysis with hydrobromic acid (100 c.c.) the ester (20 g.) gave an oily mixture, which on fractional distillation yielded three fractions, (i) b. p. 200—205°/12 mm., (ii) 210—215°/17 mm., and (iii) 230—235°/17 mm. The last fraction solidified and was recrystallised from ethyl acetate; m. p. 135°; its analysis and properties indicated it to be a *dilactone* (Found: C, 61·0; H, 6·0. $C_{10}H_{12}O_4$ requires C, 61·2; H, 6·1%). The first fraction gave a semicarbazone, m. p. 184°, identical with that obtained from the ketone (I*a*, R = Me), and the second fraction gave an isomeric semicarbazone identical with the same derivative obtained from the ketone (I*b*, R = Me).

(2) A mixture of βγ-dibromopropene (100 g.), phenol (47 g.), potassium carbonate (35 g.), and acetone (200 c.c.) was refluxed for 12 hours, the solvent removed under reduced pressure, and the residue poured into water and extracted with ether. β-Bromoallyl phenyl ether, b. p. 105°/15 mm., was obtained from the ethereal residue in 70% yield (cf. Henry, *Bull. Soc. chim.*, 1883, **40**, 324).

A mixture of β-bromoallyl phenyl ether (103·8 g.), caustic potash (42 g.), and alcohol (84 c.c.) was heated on a water-bath for 3 hours, the solution poured into water, and the oily liquid separated with ether. On distillation phenyl propargyl ether, b. p. 95—98°/23 mm., was obtained in 40% yield (cf. Henry, *loc. cit.*).

Phenyl propargyl ether (13·5 g.) was heated with finely pulverised sodium (23 g.) in toluene (100 c.c.) on a water-bath for 6 hours, the sodio-derivative separated by decantation and suspended in dry ether (200 c.c.), and, with cooling in a freezing mixture, a solution of acetyl chloride (10 g.) in ether (30 c.c.) slowly added. The mixture was left at room temperature for 2 days and poured into ice-water, and the product extracted and dried in ether, and distilled up to 150°/20 mm. The residue consisted mainly of *phenoxypropynyl methyl ketone* (VII, R = Me) and was used for further reactions; the specimen for analysis was twice redistilled, b. p. 164—166°/20 mm. (Found: C, 75·8; H, 5·7. $C_{11}H_{10}O_2$ requires C, 75·9; H, 5·8%). The *semicarbazone*, m. p. 135°, crystallised from dilute alcohol (Found: C, 62·2; H, 5·4; N, 18·0. $C_{12}H_{13}O_2N_3$ requires C, 62·3; H, 5·6; N, 18·2%).

The acetylenic ketone (1 mol.) was refluxed with ethyl sodiomalonate (2·3 g. of sodium, 16 g. of ethyl malonate, and 30 c.c. of alcohol) for 6 hours, ethyl iodide (16 c.c.) then added, and the mixture refluxed until it became neutral. After removal of the solvent and the excess of ethyl iodide under reduced pressure the residue was mixed with a fresh quantity of alcohol (100 c.c.) and hydrogenated in presence of palladised charcoal (Paal and Hartmann, *loc. cit.*) until 1 mol. of hydrogen was absorbed. The solvent was then removed, and the residue hydrolysed with excess of fuming hydrobromic acid. The product after separation with ether gave on distillation mainly two fractions, (i) b. p. 194—200°/17 mm., and (ii) 200—205°/17 mm., identified with the ketones (I*a*, R = Me) and (I*b*) by means of their semicarbazones.

β-Benzylideneacetonyl-α-ethyl-γ-butyrolactone (I*a*, R = CH:CHPh).—A mixture of the ketone (I*a*, R = Me) (10 g.) and benzaldehyde (6·5 g.) was left in 10% sodium hydroxide solution (35 c.c.) for 3 weeks with occasional shaking. The solution was then neutralised with acetic acid, steam-distilled to remove benzaldehyde, and extracted with ether. The residue from the ethereal solution was converted into semicarbazone and fractionally crystallised. Two solids separated, m. p. 245° (5·4 g.) and 211° (2 g.). The latter was identified with the semicarbazone of the benzylidene derivative obtained from the isomeric ketone (below). The former, the less soluble product, was the *semicarbazone* of β-benzylideneacetonyl-α-ethyl-γ-butyrolactone; after recrystallisation from water it melted at 245° (Found: C, 68·4; H, 6·4; N, 13·1. $C_{17}H_{21}O_3N_3$ requires C, 68·6; H, 6·7; N, 13·3%). The *benzylidene* derivative obtained from it by warming with concentrated hydrochloric acid was a viscous oil (Found: C, 74·0; H, 6·8. $C_{16}H_{18}O_3$ requires C, 74·4; H, 7·0%). This compound was also obtained by the following procedure: *γ-Homopilopoyl chloride (1 mol.) was added to a well-cooled suspension of the* sodio-derivative of phenylacetylene in ether (Nef, *Annalen*, 1909, **308**, 275), and the mixture shaken on a machine. After 48 hours the solvent was removed, and the residue suspended in alcohol (200 c.c.) and hydrogenated in presence of palladised charcoal (Paal and Hartmann, *loc. cit.*) until 1 mol. of hydrogen was absorbed. The alcohol was then distilled, and the residue extracted with ether. After removal of the ether from the extract the residue was steam-distilled to remove the admixed styrene, washed and dried in ether, and recovered as a thick

liquid, which was identified with the above liquid benzylidene derivative by means of its semicarbazone (yield, 30%).

iso-*β-Benzylideneacetonyl-α-ethyl-γ-butyrolactone* (Ib, R = CH:CHPh).—When the ketone (Ib, R = Me) was treated with benzaldehyde and sodium hydroxide solution in the way already described, the *butyrolactone* (Ib, R = CH:CHPh) was the sole product (yield, 45%); after crystallisation from ethyl acetate–benzene, it had m. p. 105° (Found: C, 74·1; H, 6·7%). The *semicarbazone* crystallised from alcohol in thick needles, m. p. 211° (Found: C, 68·4; H, 6·5; N, 13·5%). The preparation from *r-iso*homopilopoyl chloride and sodiophenylacetylene gave ultimately only a 10% yield of the benzylidene derivative.

Ozonolysis of the Benzylidene Derivatives (Ia and b, R = CH:CHPh).—Ozone was passed through a solution of the benzylidene derivative (Ia) (10 g.) in chloroform (250 c.c.) until no more was absorbed; the solvent was then removed in a vacuum at the ordinary temperature. The residue was dissolved in ether (250 c.c.) and glacial acetic acid (10 c.c.), cooled in a freezing mixture, and decomposed with zinc (10 g.) and water (5 c.c.), added with vigorous stirring during 1 hour. The sludge was removed, the filtrate washed with dilute sodium bicarbonate solution and water and dried, the solvent removed under reduced pressure at the ordinary temperature, and the residue steam-distilled to remove benzaldehyde. The residual solution of *α-ethyl-γ-butyrolactone-β-pyruvaldehyde* (IXa) was used for further reactions. The pure glyoxal (2·2 g.), however, was obtained by extraction with ether and removal of the ether at the ordinary temperature by dry carbon dioxide; it was a thick oil, which reduced ammoniacal silver nitrate and gave a non-crystalline osazone (Found: C, 58·2; H, 6·2. $C_9H_{12}O_4$ requires C, 58·7; H, 6·5%).

The benzylidene derivative (Ib, R = CH:CHPh) similarly gave an isomeric *glyoxal* derivative (IXb) in almost equal yield (Found: C, 58·4; H, 6·2%). This formed an *osazone* which separated from dilute alcohol in lemon-coloured crystals, m. p. 156° (Found: C, 69·0; H, 6·1; N, 15·7. $C_{21}H_{24}O_2N_4$ requires C, 69·2; H, 6·6; N, 15·4%).

Synthesis of r-*Pilocarpidine* (Xa).—The glyoxal (IXa) (2 g.) or an aqueous solution containing it was mixed with a solution of ammonia (2 c.c., *d* 0·880, specially prepared by saturating carbon dioxide-free water with the gas) and formaldehyde (2 c.c.; 40%). After 3 weeks the solution was evaporated under reduced pressure at 60°, the residue acidified strongly with hydrochloric acid and boiled for 2 hours, the solution again evaporated to dryness under reduced pressure, and the residue mixed with a concentrated solution of potassium carbonate and extracted with chloroform in a continuous extractor. On evaporation of the dried chloroform solution a thick oily base was left; this was converted by the calculated amount of nitric acid into the nitrate, m. p. 131° after crystallisation from alcohol (Found: C, 46·6; H, 5·5; N, 16·5. Calc. for $C_{10}H_{14}O_2N_2,HNO_3$: C, 46·7; H, 5·5; N, 16·3%).

Synthesis of r-iso*Pilocarpidine* (Xb).—In the same manner the glyoxal (IXb) (2 g.) or a solution of it in water furnished *r-iso*pilocarpidine, of which the nitrate had m. p. 113—114° after repeated crystallisation (Found: C, 46·5; H, 5·2; N, 16·2%).

These two bases, when methylated with methyl iodide in the usual way, severally gave *r*-pilocarpine [nitrate, m. p. 150° after repeated crystallisation (Found: C, 48·5; H, 6·3; N, 15·4. Calc. for $C_{11}H_{16}O_2N_2,HNO_3$: C, 48·7; H, 6·3; N, 15·3%)] and *r-iso*pilocarpine [nitrate, m. p. 132—134° after recrystallisation from alcohol (Found: C, 48·4; H, 6·1; N, 15·1%)].

Resolution of r-*Pilocarpine*.—When a solution of *l*-tartaric acid (1 mol.) in just sufficient alcohol to dissolve it was added to a solution of *r*-pilocarpine (0·9 g.; 2 mols.) in alcohol (5 c.c.), *d*-pilocarpine hydrogen *l*-tartrate was precipitated as an oil which soon solidified; after recrystallisation from dilute alcohol it had m. p. 132° alone or mixed with the same salt of natural pilocarpine (Found: C, 50·0; H, 6·0; N, 7·8. Calc. for $C_{11}H_{16}O_2N_2,C_4H_6O_6$: C, 50·3; H, 6·2; N, 7·8%). The base obtained from the hydrogen tartrate was converted into the nitrate, which, after recrystallisation from dilute alcohol, melted at 175°, alone or mixed with the same salt of natural pilocarpine (Found: C, 48·5; H, 6·0; N, 15·6. Calc. for $C_{11}H_{16}O_2N_2,HNO_3$: C, 48·7; H, 6·3; N, 15·5%). It had $[\alpha]_D^{19°}$ 81·3° in water (c = 1·165, l = 0·5).

The filtrate from the *d*-pilocarpine hydrogen *l*-tartrate was treated with an equal quantity of *d*-tartaric acid (1 mol.) and the precipitate (0·25 g.) of *l*-pilocarpine hydrogen *d*-tartrate was filtered off and recrystallised from alcohol; m. p. 132° (Found: C, 49·9; H, 6·2; N, 7·9%). The base obtained from it after repeated crystallisation was converted into the nitrate, m. p. 175° after crystallisation from alcohol (Found: C, 48·5; H, 6·0; N, 15·6%). It had $[\alpha]_D^{19·5°}$ = −82·17° in water (c = 0·925, l = 0·5).

The pure active bases (0·005 g. of each) were mixed together in dry ether; the base recovered

by evaporation of the solution under reduced pressure was converted into the nitrate, m. p., after recrystallisation, 150° alone or mixed with the nitrate of *r*-pilocarpine.

Conversion of l-*Pilocarpine into* l-iso*Pilocarpine.*—*l*-Pilocarpine (0·25 g.) was mixed with an alcoholic solution of sodium ethoxide (0·3 g. of sodium in 20 c.c. of alcohol) and after a few days the mixture was warmed for 1 hour on the water-bath, the alkali neutralised with alcoholic hydrochloric acid, the solution evaporated under reduced pressure, and the residue made strongly alkaline with sodium carbonate solution and extracted with chloroform. The base obtained from the dried chloroform solution was converted into the nitrate, m. p. 156—158° (dilute alcohol) (Found: C, 48·5; H, 6·0; N, 10·1. Calc. for $C_{11}H_{16}O_2N_2,HNO_3$: C, 48·7; H, 6·3; N, 10·3%). It had $[\alpha]_D^{17·0°}$ − 53·1° in water (*c* = 1·216, *l* = 0·5). The *r*-base obtained from the two active *iso*pilocarpines in ether formed a nitrate, m. p. 134° alone or mixed with *r*-*iso*pilocarpine nitrate.

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223. *The Formation of Diene Hydrocarbons. Part I. Principles relating to the Course of Reaction in the Dehydration of Unsaturated Alcohols. The Co-formation of αα- and αγ-Dimethylbutadiene.*

By Reginald G. R. Bacon and Ernest Harold Farmer.

It is known that, when a secondary alcohol of the type R·ĊH·Ċ(OH)·ĊHR′ is dehydrated, there may in general be formed two olefins, R·Ċ:Ċ·ĊHR′ and R·ĊH·Ċ:ĊR′. Analogously, from tertiary alcohols CRR′R″·OH, three olefins may in general be formed, provided that the first carbon atoms of the groups R, R′ and R″ possess the necessary hydrogen atom for elimination.* Church, Whitmore, and McGrew (*J. Amer. Chem. Soc.*, 1934, **56**, 176), as the result of quantitative experiments with twenty-two alkylcarbinols, arrange the commoner alkyl radicals in the order of their tendency to contribute a hydrogen atom for elimination with hydroxyl: this order (Et > Bu$^{\alpha}$ > *n*-C_5H_{11} > Me) agrees, except in the case of methyl, with that recorded by Ingold (J., 1927, 997) for the tendency to contribute hydrogen for elimination with the basic group in the somewhat analogous Hofmann degradation:

$$R·CH(H)·CH_2·\overset{\oplus}{N}Me_2·CH_2·CH(H)·R' \begin{cases} \rightarrow R·CH{:}CH_2 + \overset{\oplus}{N}HMe_2·CH_2·CH_2R' \\ \rightarrow R'·CH{:}CH_2 + \overset{\oplus}{N}HMe_2·CH_2·CH_2R \end{cases}$$

The dehydration of alcohol systems R·ĊH·Ċ(OH)·ĊH·Ċ:CR′R″ and R·ĊH·Ċ(OH)·CH:CR′R″, which already contain one double bond, has fairly generally been assumed to yield a single homogeneous diene in each case, and the same applies to certain diols which give up their hydroxyl groups successively or simultaneously to form conjugated dienes. Yet in these examples also, theoretical considerations point clearly to the possibility that dehydration at each secondary alcohol centre may occur in either or both of two directions, so that, from an alcohol such as dimethylallylcarbinol (I),

$$\underset{\text{(III.)}}{CMe_2{:}CH·CH{:}CH_2} \longleftarrow \underset{\text{(I.)}}{CH_3·CMe(OH)·CH_2·CH{:}CH_2} \longrightarrow \underset{\text{(II.)}}{CH_2{:}CMe·CH_2·CH{:}CH_2}$$

either the non-conjugated diene (II) or its conjugated isomeride (III), or both, may be produced. These courses of reaction take no account of "abnormal" shifts of double

* Eliminations which are made possible by the migration of alkyl groups, such as occur during the dehydration of *tert.*-butylcarbinol (Whitmore, *J. Amer. Chem. Soc.*, 1933, **55**, 1106, 3721), are not here considered.

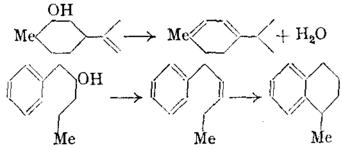
bonds, such as have been reported by Dumoulin (*Compt. rend.*, 1926, **182**, 974) and Merling (*Annalen*, 1891, **264**, 342) respectively to occur in the pyrolytic eliminations (1) and (2),

(1) $CH_2{:}CH{\cdot}CH(OH){\cdot}C_3H_7 \longrightarrow CH_2{:}CH{\cdot}CH{:}CHEt + CHMe{:}CH{\cdot}CH{:}CHMe$

(2) $CH_2{:}CH{\cdot}[CH_2]_4{\cdot}NMe_3{\cdot}OH \longrightarrow CH_2{:}CH{\cdot}[CH_2]_2{\cdot}CH{:}CH_2 + CHMe{:}CH{\cdot}CH_2{\cdot}CH{:}CH_2$

or of the seemingly erratic movements of double bonds which are a feature of certain terpene dehydrations, as, for instance, that represented in (3), and of various dehydrative ring-closures described by Bogert (*J. Amer. Chem. Soc.*, 1935, **57**, 151) exemplified in (4). If an "abnormal" double bond displacement of this kind were to occur in dimethylallyl-

(3)
(4)



carbinol, a third diene hydrocarbon, $CH_2{:}CMe{\cdot}CH{:}CHMe$ (IV), could arise, but it is difficult in reviewing recorded examples to discriminate between degrees of abnormality, *i.e.*, to judge how far such displacements are the direct result of deep-seated molecular disturbance occasioned by high temperatures, or are normal features of specific dehydrative mechanisms. The displacement of the double bond shown in (3) does not occur when dehydration is accomplished by the xanthic ester method, and there is no evidence to show that the principles of reaction which govern eliminations effected under mild conditions remain trustworthy for the very numerous dehydrations which can be brought about at comparatively high temperatures in the presence of contact reagents; moreover it is not established that the different "mild" dehydrating agents of the ordinary types, each acting with its own degree of ease or success, give exactly the same product or mixture of products for the same alcohol. It appears very necessary, therefore, in attempting to trace the influence of structure on the course of dehydration to have due regard to the experimental process employed, and for this reason comparisons in this paper are restricted to dehydrations which result from the employment of a single experimental procedure (*viz.*, refluxing the alcohol with a few drops of concentrated hydrobromic acid), although later it is hoped to investigate and compare the results of other procedures.

Although dimethylallylcarbinol (I) itself does not appear to have been dehydrated previously, M. and A. Saytzew (*Annalen*, 1877, **185**, 151) obtained a hydrocarbon C_6H_{10} by the action of alcoholic potash on the corresponding chloride, and Ljubarsky (*J. pr. Chem.*, 1900, **62**, 657) prepared a hydrocarbon (b. p. 60—78°) by the same method and suggested that the essential elimination product was either (II) or (III). Diels and Alder (*Annalen*, 1929, **470**, 62) prepared a hydrocarbon by Saytzew's method and obtained therefrom a small yield of the maleic anhydride derivative of αγ-dimethylbutadiene (IV).

The product of dehydration of dimethylallylcarbinol, with hydrobromic acid as catalyst, has been found by us to consist entirely of diene hydrocarbons C_6H_{10}. From the mixture, a substantially complete separation of a relatively low-boiling, non-conjugated hydrocarbon (b. p. 57—58°/766 mm.) can be effected without difficulty by fractionation, and this by reason of its physical properties, chemical reactivity, and the nature of its degradation products (see p. 1072) can be definitely identified as β-methyl-$\Delta^{\alpha\delta}$-pentadiene (II). The residue is still heterogeneous, the physical properties of its fractions changing progressively over a boiling range of 4° (b. p. 73·0—76·7°; $n_D^{13\cdot5°}$ 1·4464—1·4513).

The hydrocarbons to be expected in the residue are of course αα- and αγ-dimethylbutadiene (III and IV), both of them conjugated. The molecular refraction of the residue was in fact sufficiently high to point to a wholly conjugated (albeit heterogeneous) constitution, but since reasonably efficient separation of the components by the best columns and with the bulk of material at disposal proved to be out of the question the course was

adopted of examining the mixture side by side with a series of heterogeneous products, all somewhat different in physical properties, obtained by dehydration of various alcohols and glycols which from their structure might have been expected to yield the αα-hydrocarbon. The results obtained with the latter are described below (p. 1070) in detail; it is sufficient here to state that the products in *all* these cases consisted of mixtures in different proportions of two conjugated dienes differing little in boiling point. In the dimethylallylcarbinol product one of the hydrocarbons was easily identifiable as αγ-dimethylbutadiene by the formation of its characteristic unimolecular derivative with maleic anhydride and an approximate estimate of its proportion in the mixture could be made from the yield of this derivative when formed at room temperature in benzene solution * (compare Farmer and Warren, J., 1931, 3234).

The identification of the remaining hydrocarbon as the αα-compound was rendered difficult by the fact that the four † preparations of this hydrocarbon described in the literature, although undoubtedly all of essentially dienic constitution and agreeing fairly closely in boiling point, yet differed from one another materially in their other physical properties and all remained uncharacterised by the formation of a crystalline derivative. Three of these, however, were derived by different workers (Bruylants, *Bull. Acad. roy. Belg.*, 1908, 1044; van Keersbilck, *Bull. Soc. Chim. Belg.*, 1929, **38**, 205; Farmer and Warren, *loc. cit.*, p. 3221) from the tertiary alcohol (V) *via* a bromide of the reputed constitution (VI), and there can be slight doubt that the main product in each case, whether the αα-hydrocarbon or not, was the same substance.

$$\underset{\text{(V.)}}{\begin{matrix}CH_2\\|\\CH_2\end{matrix}\!>\!CH{\cdot}CMe_2{\cdot}OH} \xrightarrow{\text{HBr}} \underset{\text{(VI.)}}{CH_2Br{\cdot}CH_2{\cdot}CH{:}CMe_2} \xrightarrow[\text{(alc.)}]{\text{NaOH}} \underset{\text{(III.)}}{CH_2{:}CH{\cdot}CH{:}CMe_2}$$

The fourth preparation, due to Krestinski (*Ber.*, 1922, **55**, 2754), was obtained in very small amount by the dehydration with acetic anhydride of what was unquestionably mainly the alcohol (VII) (synthesised from *iso*butenylmagnesium bromide and acetaldehyde) ‡ and this may well have resembled the other three as regards the main component, but have

$$CMe_2{:}CH{\cdot}MgBr + CH_3{\cdot}CHO \longrightarrow \text{(VII)}\ CMe_2{:}CH{\cdot}CHMe{\cdot}OH \longrightarrow \text{(III)}$$

differed therefrom in the proportion of other hydrocarbons present. Of the three preparations derived from the alcohol (V), the most satisfactory as regards freedom from foreign hydrocarbons and impurities is probably that obtained in considerable quantity by one of us (Farmer and Warren, *loc. cit.*). It differed in boiling point from its αγ-isomeride by 1° and was unique among the seven monomethyl- and dimethyl-butadienes in giving only a polymeric (amorphous or microcrystalline) derivative with maleic anhydride.

In the present case the crude maleic anhydride derivative obtained from the residual mixture of conjugated hydrocarbons contained, in addition to the characteristic crystalline derivative of the αγ-hydrocarbon, a quantity (at least 20%) of waxy polymeric anhydride, and the oxidation products from various fractions of the conjugated residue contained in notable proportions acetone and oxalic acid (in addition to formic and acetic acids) which could only have been derived from the αα-hydrocarbon. Since the hydrogenation figures obtained experimentally precluded the possibility that a completely foreign hydrocarbon was also present in significant quantity, we must conclude that the conjugated portion of the dehydration product of dimethylallylcarbinol consisted of a mixture of αα- and αγ-dimethylbutadienes.

Thus all the courses of dehydration foreshadowed above, including that in which the original double bond of dimethylallylcarbinol becomes displaced, are realised in practice, and since the hydrocarbons (II), (III), and (IV) are formed in roughly the proportions 50%, 10%, and 40%, it seems clear that, although in the system $CH_2{:}CH{\cdot}CH_2{\cdot}CMe(OH){\cdot}CH_3$ elimination can occur in both of the possible directions, *i.e.*, by removal of the hydroxyl

* The maleic anhydride derivative of αγ-dimethylbutadiene undergoes polymerisation on long standing.

† This number does not include several preparations described as the αα-compound which it is now clear must have consisted almost entirely of the αγ-hydrocarbon (see below).

‡ For the synthesis of this alcohol by a more reliable method and its dehydration by hydrogen bromide, see below.

group with a proton from either C_3 or C_5, yet owing to the influence (electron-donating) of the adjacent vinyl group the hydrogen atom on C_3 is so firmly held that removal of the proton from C_5 becomes capable of proceeding on preferential terms. But this relatively difficult removal (C_5 being part of a terminal methyl group) only succeeds at the expense of provoking a molecular disturbance sufficiently intense to allow the inherent conjugative tendency of the molecules (involving double-bond shift) to assert itself.

In addition to the principles of dehydration considered above, comprising (1) elimination of the elements of water in all the normally possible directions and (2) a capacity in certain cases for the occurrence of some degree of "abnormal" double bond displacement directed towards the achievement of conjugation, there is a third principle of elimination to be taken into account. This concerns the capacity of structures containing the group C:C·CX, where X = OH, Br, etc., to undergo $\alpha\gamma$-change, and results in the phenomenon of certain alcohols behaving on dehydration partly or wholly as their isomeride. Our experience has already shown that this third principle is of great practical importance, and in extreme cases (extreme from the standpoint of reactivity) it is responsible for a secondary or tertiary alcohol behaving as an isomeric primary alcohol. A good example for investigation appeared to be ϵ-methyl-Δ^{β}-hexen-δ-ol (VIII), which in its isomeric form would be the β-methyl-Δ^{γ}-hexen-ϵ-ol (IX). Having regard to the activation value of the groups

$$\text{(VIII.) } CHMe_2{\cdot}CH(OH){\cdot}CH{:}CH{\cdot}CH_3 \xrightarrow{\alpha\gamma\text{-change}} CHMe_2{\cdot}CH{:}CH{\cdot}CH(OH){\cdot}CH_3 \text{ (IX.)}$$

$$\downarrow -H_2O \qquad\qquad\qquad\qquad \downarrow -H_2O$$

$$\text{(X.) } CMe_2{:}CH{\cdot}CH{:}CH{\cdot}CH_3 \qquad\qquad CHMe_2{\cdot}CH{:}CH{\cdot}CH{:}CH_2 \text{ (XI.)}$$

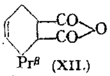
(Pr^{β} and Me) substituting the basic 3-carbon system of (VIII), the anion of (VIII) might be expected to pass largely (> 50%) into that of (IX) with the result that a mixture of $\alpha\alpha\delta$-trimethylbutadiene (X) and α-*iso*propylbutadiene (XI), the latter compound preponderating, would ultimately appear on dehydration.

According to Reif (*Ber.*, 1908, **41**, 2739) the alcohol (VIII) is dehydrated by potassium hydrogen sulphate to give in very poor yield a hydrocarbon, b. p. 97—99°, regarded as (X). We have found, however, that dehydration proceeds very efficiently in presence of hydrobromic acid to give a hydrocarbon, b. p. 99—112°. This hydrocarbon was wholly dienoid in character, but all the fractions obtained on distillation consisted of mixtures of two different hydrocarbons, the one concentrated towards the lower-boiling limit and the other towards the upper. The former of these was recognised as α-*iso*propylbutadiene (XI) and the latter as $\alpha\alpha\delta$-trimethylbutadiene (X). Both hydrocarbons (X) and (XI) are capable of exhibiting geometrical isomerism, so four stereo-forms were probably present in the mixture, thus rendering a clear-cut separation of the two structural isomerides impossible on the scale of working used. The identity of the two hydrocarbons rests on analysis, hydrogen or bromine value, and the following evidence:

(1) All the fractions yielded formic acid (from XI) and all yielded acetone (from X) on oxidation; moreover the yield of acetone increased markedly on passing from the lower- to the higher-boiling fractions.

(2) From no fraction could *pure* acetic acid be obtained as an oxidation product: it was always contaminated by another acid of higher equivalent, and from the lowest-boiling fraction of hydrocarbon *iso*butyric acid (from XI) was isolated in the form of its silver salt.

(3) The mixture of hydrocarbons yielded two products with maleic anhydride, *viz.*, a new crystalline derivative, $C_{11}H_{14}O_3$, m. p. 90° (A), and a polymeric product (B). The higher-boiling fraction yielded (B) practically exclusively and the lower fractions largely (A), but with an amount of (B) which increased as the boiling point of the fractions rose.



(XII.)

The last observation, taken in conjunction with the oxidation results above, left little doubt that the crystalline derivative was derived from (XI) and was in fact 3-*isopropyl-Δ^4-tetrahydrophthalic anhydride* (XII), and the polymeric substance was derived from (X). This deduction is greatly strengthened by the knowledge that $\alpha\alpha$-dimethyl- as well as $\alpha\alpha\delta$-trimethylbutadiene yields only polymeric addition products with maleic anhydride, and there appears

some probability that αα-dialkyl-substitution of butadienes tends generally towards polymeric reactivity.

Although no very accurate estimate could be formed of the proportion of the isomeric dienes obtained from the alcohol (VIII), yet both were evidently produced in substantial amount. The occurrence of αγ-change, of which other examples are given below, must therefore be accepted as a normal concomitant of dehydration in those cases where the structure of the alcohol and the conditions of dehydration permit it. The homogeneity, therefore, of many dienoid hydrocarbons described in the literature which have been derived from precursors susceptible of αγ-change must be regarded with suspicion. It must be borne in mind, however, that in all dehydration processes employing catalysts such as hydrobromic acid and iodine, esterification is usually held to constitute the first stage of reaction (the bromide, iodide or other ester group being more readily ionisable and detachable than the original hydroxyl group) and this mechanism gives free play to the anionotropic tendency; yet under other conditions of reaction it appears possible that elimination may be able to proceed by a more direct route or at least by one which largely or entirely prevents the occurrence of αγ-change.

Although in general the employment of saturated glycols in place of unsaturated alcohols leads normally to an increased degree of structural variation in the dehydration products, yet there is one particular example of glycol dehydration which is of special interest in relation to the foregoing results. Kyriakides investigated the dehydration of β-methylpentane-βδ-diol (XIII) and δ-methyl-Δ^{β}-penten-δ-ol (XIV), using hydrobromic acid as catalyst, and reported that he had obtained αα- and αγ-dimethylbutadiene (III and IV) in the

$$\underset{\text{(XIII.)}}{CMe_2(OH){\cdot}CH_2{\cdot}CHMe{\cdot}OH} \longrightarrow \underset{\text{(XV.)}}{CMe_2{:}CH{\cdot}CHMe{\cdot}OH} \longrightarrow \underset{\text{(III.)}}{CMe_2{:}CH{\cdot}CH{:}CH_2}$$

$$\text{(XIV.)}\quad CHMe{:}CH{\cdot}CMe_2{\cdot}OH \longrightarrow CHMe{:}CH{\cdot}CMe{:}CH_2 \quad \text{(IV.)}$$

respective cases (*J. Amer. Chem. Soc.*, 1914, **36**, 993). In the course of the former dehydration an unsaturated alcohol appeared as a by-product (presumably an intermediate product), and this was assumed to consist mainly of the compound (XV), since the formation of the isomeric alcohols $CMe_2(OH){\cdot}CH_2{\cdot}CH{:}CH_2$ and $CMe_2(OH){\cdot}CH{:}CHMe$, arising by dehydration at the secondary instead of at the tertiary carbinol group, was not considered to be highly probable. It was recognised, however, that the alcohol $CH_2{:}CMe{\cdot}CH_2{\cdot}CHMe{\cdot}OH$ represented another possible intermediate, and this would finally be dehydrated to produce αγ-dimethylbutadiene, so causing contamination of the main hydrocarbon product. In the case of the second dehydration (XIV ⟶ IV), a pure product was considered to result, since there were no obvious side-reactions.

The product of dehydration of the glycol (XIII), however, appeared on subsequent examination (Diels and Alder, *Annalen*, 1929, **470**, 98; Farmer, Lawrence, and Scott, J., 1930, 511) to be not αα- but αγ-dimethylbutadiene, and to be indistinguishable in its essential chemical behaviour (especially in the formation of the crystalline derivative with maleic anhydride) from the hydrocarbon from (XIV). A little later Whitby and Gallay (*Canadian J. Res.*, 1932, **6**, 280), in publishing the results of a study of the heat-polymerisation of a number of dimethylbutadienes, claimed that the hydrocarbons derivable by the Kyriakides method from the compounds (XIII) and (XIV) were indeed distinct hydrocarbons (*i.e.*, αα- and αγ-dimethylbutadiene respectively), differing in physical properties, in speed of polymerisation, and in the nature of their polymerides. It was admitted that the dehydration product of the glycol might conceivably contain a little of the αγ-hydrocarbon, but it was believed to consist preponderantly of αα-dimethylbutadiene.

The conclusions of the Canadian workers may be criticised in that (1) no direct experimental evidence for the constitution of their hydrocarbons was adduced, (2) their specimens did not differ sufficiently in physical properties to suggest any marked difference in composition, and (3) the polymerisations were carried out with only 10 g. portions of the hydrocarbons, of which 57% polymerised in the case of the supposed αα-compound and 51% in that of the αγ-isomeride. The polymeric products they obtained were separated into dimeric and rubber-like components, which exhibited certain physical differences in the

two cases; but, bearing in mind the small quantities of materials employed and how greatly the course of polymerisation may be affected by the presence of traces of impurities, it cannot be claimed that the experiments in question were highly conclusive.

A new detailed study of the dehydration products of the glycol (XIII) and the unsaturated alcohol (XIV) provides adequate evidence for rejecting unhesitatingly the contention of Whitby and Gallay with respect to the main dehydration product from (XIII). The hydrocarbon products from both (XIII) and (XIV) have been obtained again in considerable quantities and submitted to rigid fractionation in Widmer or bead-packed columns. The two products resembled fairly closely the conjugated portions of the dehydration product from dimethylallylcarbinol described above, except that the range of boiling point, and other of the physical properties, differed appreciably in the three individual cases. Since the boiling point was in no instance sharp and the successive fractions obtained by distillation showed progressive small differences in physical properties, it was clear that the dehydration products of (XIII) and (XIV), like that of dimethylallylcarbinol, were mixtures, although that from (XIV) was heterogeneous only in minor degree. The main product in each case was unquestionably $\alpha\gamma$-dimethylbutadiene and an approximate estimate of the proportion of this hydrocarbon present could be made by isolating it in the form of its pure maleic anhydride derivative, but no satisfactory separation of the individual hydrocarbons could be made. The residual hydrocarbon, taking into consideration its empirical composition (as judged from that of the total dehydration product), physical properties, its oxidation products and ability to yield only a polymeric additive derivative with maleic anhydride under standard conditions (compare Farmer and Warren, J., 1931, 3234), must be regarded as $\alpha\alpha$-dimethylbutadiene. On the basis of the quantity of crystalline maleic anhydride derivative of the $\alpha\gamma$-compound obtainable directly from the mixture of hydrocarbons and the proportion of oxalic acid (from the $\alpha\alpha$-compound) obtained by oxidation of the same mixture, the proportions of the two dimethylbutadienes in the dehydration products of (XIII) and (XIV) are estimated to be roughly as follows: (XIII) 90%, 10%, (XIV) 95%, 5%. The appearance of the $\alpha\alpha$-hydrocarbon from (XIV) is doubtless due to the occurrence of $\alpha\gamma$-change in small degree during dehydration :

$$\mathrm{CHMe{:}CH{\cdot}CMe_2{\cdot}OH \xrightarrow{-OH^{\ominus}} CHMe{:}CH{\cdot}\overset{\oplus}{C}Me_2 \rightleftharpoons \overset{\oplus}{C}HMe{\cdot}CH{:}CMe_2 \xrightarrow{-H^{\oplus}} CH_2{:}CH{\cdot}CH{:}CMe_2}$$

Another alcohol which might be expected to give $\alpha\alpha$-dimethylbutadiene on dehydration is the β-methyl-Δ^{β}-penten-δ-ol of Krestinski mentioned above, but even here the occurrence of $\alpha\gamma$-change during dehydration is rendered possible by the structure of the alcohol, although such change is likely to take place only in minor degree. The alcohol has now been prepared in a way which imports less of structural uncertainty than attaches to Krestinski's compound, *viz.*, from β-methylcrotonaldehyde, $CMe_2{:}CH{\cdot}CHO$, synthesised by the procedure of Fischer, Ertel, and Löwenberg (*Ber.*, 1931, **64**, 30), by treatment with methylmagnesium bromide.* The dehydration product obtained with hydrogen bromide differed somewhat in boiling point (well defined at 77—78°) from the three mixtures of $\alpha\alpha$- and $\alpha\gamma$-dimethylbutadiene already described. It exhibited a lower density and lower refractive index and optical exaltation than the purest available specimen of the $\alpha\gamma$-hydrocarbon. The main product arising from its interaction with maleic anhydride was a wax-like polymeride; also when oxidised with permanganate it gave abundant quantities of acetone, oxalic acid and formic acid: consequently it would appear to consist predominantly of $\alpha\alpha$-dimethylbutadiene. Nevertheless the occurrence of $\alpha\gamma$-change in any degree during dehydration would lead to the production of $\alpha\gamma$-dimethylbutadiene, and it was indeed found that the polymeric maleic anhydride derivative from the dehydration product, although it was identical in appearance and general properties with the corresponding material derived by Farmer and Warren (*loc. cit.*) from the supposedly pure $\alpha\alpha$-dimethylbutadiene formed by Bruylants' method, yet yielded on extraction with petroleum a tiny quantity of crystalline addition product identical in appearance with the highly

* It is possible that a slight degree of $\alpha\gamma$-change occurs even during the preparation of the alcohol.

characteristic derivative from αγ-dimethylbutadiene. This small specimen, however, could not be sufficiently purified for absolute identification, but the presence of a small

$$\text{(XV.)}\ CMe_2{:}CH{\cdot}CHMe{\cdot}OH \xrightarrow{-OH^{\ominus}} CMe_2{:}CH{\cdot}\overset{\oplus}{C}HMe \rightleftharpoons \overset{\oplus}{C}Me_2{\cdot}CH{:}CHMe$$

$$\downarrow -H^{\oplus} \qquad\qquad \downarrow -H^{\oplus}$$

$$CMe_2{:}CH{\cdot}CH{:}CH_2 \qquad CH_2{:}CMe{\cdot}CH{:}CHMe\ \ \text{(IV.)}$$

proportion of αγ-hydrocarbon in the dehydration product was supported by the fact that acetic acid could be definitely recognised among the oxidation products. The hydrocarbon obtained from the alcohol (XV) differed considerably in physical properties from Farmer and Warren's preparations of Bruylants' hydrocarbon, and also from Krestinski's hydrocarbon.

Still another possible method for obtaining the αα-hydrocarbon is the dehydration of δ-methyl-Δ^{α}-penten-γ-ol, $CHMe_2{\cdot}CH(OH){\cdot}CH{:}CH_2$ (XVI). This alcohol, however, could not be dehydrated at all with hydrogen bromide or iodine—a surprising circumstance in view of the fact that every other alcohol containing a secondary hydroxyl group adjacent to a double bond which had been examined was dehydrated readily in presence of these reagents. Dehydration has been accomplished in analogous structures even where the group supplying the hydrogen atom for elimination with hydroxyl is methyl: when, therefore, as in this example, an *iso*propyl group should discharge this function, elimination might be expected to proceed with great ease. It has already been shown (p. 1068) that the alcohol $CHMe_2{\cdot}CH(OH){\cdot}CH{:}CHMe$, which is analogous in constitution, is dehydrated with ease in presence of hydrogen bromide: it must be concluded, therefore, that the inactivity of (XVI) arises from the occurrence of essentially complete αγ-change during the dehydration process, the product being a primary alcohol which would not be expected to undergo dehydration under the conditions used:

$$CHMe_2{\cdot}CH(OH){\cdot}CH{:}CH_2 \xrightarrow{-OH^{\ominus}} CHMe_2{\cdot}\overset{\oplus}{C}H{\cdot}CH{:}CH_2 \rightleftharpoons CHMe_2{\cdot}CH{:}CH{\cdot}\overset{\oplus}{C}H_2 \xrightarrow{Br^{\ominus}} CHMe_2{\cdot}CH{:}CH{\cdot}CH_2Br$$

Up to the present, therefore, homogeneous αα-dimethylbutadiene has almost certainly never been isolated unless in the instances referred to above where the diene hydrocarbon was derived from dimethyl*cyclo*propylcarbinol by the Bruylants method. The product obtainable by this method requires further examination, but since the procedure involved is expensive and extremely laborious to carry out on a scale large enough to permit of careful fractionation being attempted, the further investigation has been postponed. It appears probable from the present results that dehydration by hydrogen bromide or by iodine is unsuitable for the production of homogeneous hydrocarbons from systems capable of αγ-change, for here the reaction initiated by the catalyst is usually sufficiently slow to permit of the occurrence of extensive isomeric change before the final stage of dehydration (*i.e.*, removal of hydrion) is completed. Successful formation of a homogeneous product (and this conclusion would seem to apply especially to αα-dimethylbutadiene) is more likely to be accomplished by a rapidly proceeding mechanism or one which does not conduce to the intermediate formation of isomerisable kations. A positive indication in this direction is afforded by the apparent absence of αγ-dimethylbutadiene from the dehydration product of dimethylallylcarbinol when the dehydrating agent is phenylcarbimide (p. 1077), but further investigation of the influence of different dehydrating agencies and different elimination reactions on the constitution of the product is proceeding.

Experimental.

Preparation of Dimethylallylcarbinol (*δ-Methyl-Δ^{α}-penten-δ-ol*).—The preparation from magnesium turnings and an ethereal solution of acetone (1 mol.) and allyl bromide (1 mol.) as recommended by Jaworski (*Ber.*, 1909, **42**, 436) proved unsatisfactory. The following procedure, which incorporates Gilman and McGlumphy's precautions for the conduct of organometallic reactions where the halide is olefinic (*Bull. Soc. chim.*, 1928, **43**, 1322), was used with

invariable success for the preparation in good yield of large quantities of the carbinol : Finely powdered magnesium of good quality (73 g.; 3 mols.) was covered with ether (200 c.c.), and allyl bromide (121 g.; 1 mol.), dissolved in ether (570 c.c.), added with vigorous stirring during 4 hours; the solvent continued in gentle ebullition throughout the reaction. The Grignard reagent was treated with acetone (1 mol.) at − 10° in the usual manner. From the product, after working up, a liquid was obtained most of which distilled without dehydration at 32—36°/12 mm. (yield, 60—65%), and the remainder, a more viscous, deep yellow liquid, without marked break at 70—140°/12 mm. The lower-boiling liquid was dimethylallylcarbinol, and after further rectification at atmospheric pressure boiled at 117—119°/775 mm. It was a colourless liquid of characteristic and pleasant odour, $d_{4°}^{17·0°}$ 0·8326, $n_D^{17·0°}$ 1·4277; whence $[R_L]_D$ 30·90 (calc., 30·97).

Dehydration with Hydrobromic Acid.—The following procedure is of general application to alcohols which undergo dehydration on heating with hydrobromic acid; in some cases, however, reaction proceeds very slowly. The alcohol was refluxed with concentrated hydrobromic acid (usually 1 c.c. per 100 g. of alcohol) in a flask surmounted by a long column of rod-and-disc or Lessing-ring type. Heating was so adjusted that the unchanged alcohol condensed in the column and returned to the flask while the mixture of hydrocarbon and water distilled over (see Kyriakides, *J. Amer. Chem. Soc.*, 1914, **36**, 987). The hydrobromic acid was renewed from time to time, as some was slowly lost by distillation, the aqueous distillate being found to give the reactions of a bromide, and a further part was used up in subsidiary reactions which produced a little tarry material. When all distillable material had been driven over, the organic layer of the distillate was returned to the cleaned flask, the hydrocarbon fraction distilled over, and the residue submitted afresh to dehydration with more hydrobromic acid. After two such re-treatments dehydration had usually reached its limit. Iodine could generally be substituted for hydrogen bromide (compare Hibbert, *J. Amer. Chem. Soc.*, 1915, **37**, 1749) with almost identical results; possibly the former is slightly the less efficient, but the difference is extremely small.

The dehydrated product was roughly dried and the crude hydrocarbon separated from it by distillation was shaken (usually 20 times) with water to remove the residual traces of alcohol, kept overnight with sodium, and finally distilled over sodium, preferably in an atmosphere of nitrogen.

Dehydration Products of Dimethylallylcarbinol.—Dehydration attained at least 90% completion after three treatments with hydrobromic acid. The hydrocarbon on distillation through an 18-inch fractionating column packed with glass beads gave a total yield of 70%, of which 54% distilled at 62—69° and 46% at 69—77°. The hydrocarbon was redistilled through a Widmer column and collected in seven fractions each of approximately 2° range, the whole passing over between 62° and 77°. These fractions were distilled separately through the above-mentioned 18-inch column, whereon it became evident that the dehydration product consisted of a considerable proportion of a hydrocarbon boiling below 60° mixed with a second hydrocarbon boiling above 73°. When the fractionation had been repeated four times, the material had been separated into three portions: (1) Low-boiling hydrocarbon (b. p. 55—60°), 37%; (2) intermediate fraction (b. p. 60—73°), 20%; (3) high-boiling hydrocarbon (b. p. 73—75·8°), 43%. Further distillation of the fractions (1) and (3) indicated that the boiling points of their major components were 57—58°/766 mm. and 74·5—75·5°/766 mm. respectively.

Low-boiling hydrocarbon. The material of b. p. 57—58° took up, on exhaustive hydrogenation, 1·99 mols. of gas per mol. (82 g.) of hydrocarbon. It also absorbed 2 mols. of bromine in 1—2 hours, giving a colourless oily bromide, when treated with the reagent in chloroform at 0°. A satisfactory bromine figure could not, however, be obtained by the method of Rosenmund and Kuhnhenn (*Ber.*, 1923, **56**, 1262): the total absorption of bromine increased with prolongation of the period of treatment; *e.g.*, 2·86 atoms of bromine per molecule were absorbed in 2 mins., and 3·35 atoms in 2 hours.

The hydrocarbon had $d_{4°}^{17·0°}$ 0·6960 and $n_D^{17·0°}$ 1·4081, whence $[R_L]_D$ 29·10 (calc. for C_6H_{10}, 28·97). It was clear, therefore, that the double bonds in the molecule were not conjugated. This conclusion was confirmed by the fact that the hydrocarbon would not react at all with maleic anhydride under the usual conditions of addition.

Oxidation of the hydrocarbon was conducted by adding 3% permanganate solution (10 atoms of oxygen) to a vigorously stirred aqueous suspension thereof at 0°. The product, after being kept for several hours at room temperature, was freed from manganese mud by filtration, and the alkaline filtrate distilled. The distillate was collected in small fractions until no more organic material passed over. The absence of acetone (which usually passes over completely in the first 100 c.c. of distillate) and of other volatile carbonyl compounds from these fractions was shown

by means of 2 : 4-dinitrophenylhydrazine. The volatile liquid acids produced by oxidation were obtained by acidifying the alkaline liquor with sulphuric acid and distilling the product until solid began to be deposited in the flask. The distillate was neutralised with caustic soda and evaporated to dryness and from the solid residue the free fatty acids were liberated by careful acidification. The acids were conveniently identified by addition of silver nitrate to a portion of the neutralised liquor. The white precipitate thus formed in good yield was filtered off quickly : it blackened on standing. The blackening, due to the production of silver from silver formate, was completed by suspending the precipitate in water and boiling. The hot solution, freed from silver by filtration, deposited characteristic lustrous plates of silver acetate (Found : Ag, 64·6. Calc. for $C_2H_3O_2Ag$: Ag, 64·65%). Confirmation of the formation of formic acid was obtained by reducing a portion of the mixed volatile acids with magnesium and hydrochloric acid and applying the usual tests to the formaldehyde produced. The non-volatile acid produced by oxidation, in this case oxalic acid, was obtained in good yield (nearly 1 mol.) by precipitation as the calcium salt from a portion of the oxidation liquor from which the volatile acids had been removed. The precipitate, containing some calcium sulphate, was estimated in the usual way with permanganate and sulphuric acid.

The three acids formed by oxidation were those to be expected from a substance (II), the acetic and oxalic acids being the normal degradation products of the first-formed acetoacetic acid. The hydrocarbon is therefore identified as β-*methyl*-$\Delta^{\alpha\delta}$-*pentadiene* (Found : C, 87·3; H, 12·7. C_6H_{10} requires C, 87·7; H, 12·3%).

Mixture of high-boiling hydrocarbons. The fraction (3) on further distillation under an 18-inch column showed progressive change in the refractive index of the fractions [(a) b. p. 73·0—74·5°, $n_D^{13\cdot5^\circ}$ 1·4464; (b) 74·5—75·2°, $n_D^{13\cdot5^\circ}$ 1·4477; (c) b. p. 75·2—75·7°, $n_D^{13\cdot5^\circ}$ 1·4493; (d) b. p. 75·7—76·3°, $n_D^{13\cdot5^\circ}$ 1·4506; (e) b. p. 76·3—76·7°, $n_D^{13\cdot5^\circ}$ 1·4513]. A large proportion of the material boiled between 74·2° and 75·0°, and this fraction gave the values $d_{4^\circ}^{17\cdot2^\circ}$ 0·7179 and $n_D^{17\cdot2^\circ}$ 1·4486, whence $[R_L]_D$ 30·64; Σ 1·67. No satisfactory separation of either of the components could, however, be effected, nor could fractions very rich in the minor component (as indicated by the production of high yields of acetone on oxidation) be isolated.

For the preparation of derivatives and for quantitative oxidation experiments, samples were taken from the united fractions (b. p. *ca.* 74—76°). Reactions with maleic anhydride in benzene solution at room temperature did not proceed to completion, even after a week. The solid product after removal of maleic anhydride (about 75% yield) consisted to at least 20% of a polymeric addition product (only slightly soluble in petroleum); the remainder crystallised from petroleum in the network of silky needles, m. p. 58° (mixed m. p. 58°), which is characteristic of the 3 : 5-dimethyl-Δ^4-tetrahydrophthalic anhydride derived from αγ-dimethylbutadiene.

Various samples of the hydrocarbon mixture were oxidised with permanganate, under the conditions described above. All gave acetone (2 : 4-dinitrophenylhydrazone, m. p. and mixed m. p. 125°) in considerable yield. Acetic acid also was obtained (Found for the silver salt : Ag, 64·5. Calc., 64·65%). The presence in all the oxidation products of considerable amounts of formic and oxalic acids (from 0·15 to 0·2 mol.) was demonstrated as above.

When submitted to exhaustive hydrogenation, the mixture took up 2·0 mols. of gas. Towards bromine it behaved as a conjugated substance : the first molecule of the reagent was absorbed rapidly, and the second much more slowly, addition being still incomplete (in benzene solution) after 2 days. The bromides were colourless oils.

Dehydration with iodine. Three distillations of dimethylallylcarbinol with small quantities of iodine resulted in 80% dehydration. The hydrocarbon obtained boiled at 58—78° (yield, 70%) and on careful fractionation gave non-conjugated and conjugated portions as above. The conjugated portion (b. p. 72—76°) gave formic, acetic, and oxalic acids on oxidation and behaved towards maleic anhydride very similarly to the corresponding portion of the dehydration product obtained with hydrobromic acid.

Dehydration Products of ε-*Methyl*-Δ^β-*hexen*-δ-*ol*.—*Preparation of* ε-*methyl*-Δ^β-*hexen*-δ-*ol*. Crotonaldehyde (105 g.), dissolved in ether (800 c.c.), was added below − 10° to *iso*propylmagnesium bromide (243 g.) contained in 1400 c.c. of ether (compare Reif, *Ber.*, 1908, **41**, 2739). The product after hydrolysis with ice-water was worked up in the usual way but without addition of acid or ammonium chloride. The crude alcohol (85 g.) was obtained in 50% yield and distilled without decomposition at 52—61°/18 mm., mainly at 55—58°. After two fractionations at atmospheric pressure it still showed rather a wide boiling range (145—150°); therefore it was fractionated once more at reduced pressure, the fraction of b. p. 55—57°/18 mm. being accepted (Reif records b. p. 139—140°/760 mm.). A specially selected sample, b. p. 55—56°/18 mm., had $d_{4^\circ}^{21\cdot4^\circ}$ 0·8372 and $n_D^{21\cdot4^\circ}$ 1·4377, whence $[R_L]_D$ 35·76 (calc., 35·58).

The residue in the flask gave on distillation an intermediate fraction of indefinite b. p. and a well-defined fraction which boiled without decomposition mainly at 164—167°/18 mm. (yield, 30 g.). The latter, after two fractionations at reduced pressure, boiled for the most part at 164—166°/21 mm. ($d_{4°}^{25 \cdot 1°}$ 0·9324, $n_D^{25 \cdot 1°}$ 1·4707). It was a neutral, colourless, unsaturated liquid which reacted violently with sodium with evolution of hydrogen (Found: C, 72·2; H, 12·05. $C_6H_{12}O$ requires C, 71·9; H, 12·1%). The molecular weight, determined cryoscopically in benzene, was 259 (calc. for $C_{12}H_{24}O_2$: *M*, 200). On hydrogenation the high-boiling alcohol absorbed 1 mol. of hydrogen per 194 g. of substance, the absorption being steady but slow; on bromination, however, a lower degree of unsaturation or higher molecular weight was indicated, 1 mol. of halogen being absorbed by 247 g. of the alcohol. The molecular refraction, $[R_L]_D$ 59·98 (calc. on the assumption that the substance contains one double bond and two hydroxyl groups, 60·20), agrees fairly well with the formula $C_{12}H_{24}O_2$, but the precise constitution and the mechanism of formation of the by-product have not been determined.

Dehydration. The alcohol (48 g.) was dehydrated with great ease in the presence of hydrobromic acid, the decomposition being practically complete in one operation. A hydrocarbon, b. p. 95—115°, was obtained in 75% yield. After preliminary distillation and thorough washing in the usual manner, the hydrocarbon was redistilled (Found: C, 87·0; H, 12·4. Calc. for C_7H_{12}: C, 87·4; H, 12·6%) and then fractionated in a Widmer column. Four fractions, *viz.*, (1) b. p. below 99°, (2) b. p. 99—105°, (3) b. p. 105—108°, and (4) b. p. 108—112°, were separated, of which (2) and (3) constituted the chief portion of the material.

A sample of each fraction was kept with a solution of maleic anhydride in benzene for over a week. On evaporation of the solvent and removal of unchanged maleic anhydride with water, the addition product from fractions (1) and (2) crystallised, but those from (3) and (4) were of a sticky or gummy nature. The crystals from (1) and (2) were soluble in petroleum and separated therefrom in lustrous plates, m. p. 90° (Found: C, 67·95; H, 7·3. $C_{11}H_{14}O_3$ requires C, 68·0; H, 7·3%), which must be regarded as 3-iso*propyl-Δ⁴-tetrahydrophthalic anhydride* (XII), but in both cases (more particularly in the product from fraction 2) the crystals were accompanied by a quantity of polymeric additive compound. A little of the crystalline derivative was present in the addition product from (3), but the bulk of this product and the whole of that from (4) were composed of polymeric material.

Oxidation. Equal quantities of the four hydrocarbon fractions were oxidised with permanganate at 0°. The neutral distillates from the oxidation products gave in every case with 2 : 4-dinitrophenylhydrazine a copious precipitate of the acetone derivative, m. p. 125—126° (mixed m. p. 125—126°); moreover the quantity of this derivative obtained increased markedly and progressively in the successive fractions 1—4, being very considerable in the case of (4). The volatile acidic products from the fractions were neutralised and precipitated with silver nitrate. The white mixtures of silver salts so obtained all blackened on standing, and on boiling with water suffered very considerable decomposition with separation of silver. From each of the decomposition products, however, an undecomposed silver salt was extracted by the boiling water and these were examined separately. That from fraction (1) crystallised in white flakes which differed from silver acetate in appearance and probably consisted of nearly pure silver *iso*butyrate (Found: Ag, 55·8. Calc. for $C_4H_7O_2Ag$: Ag, 55·35%). The silver salts similarly obtained from fractions (2), (3), and (4) separated in needle-like crystals. Their silver contents corresponded with those that would be given by silver acetate admixed with a proportion of the silver salt of an acid of higher equivalent, *e.g.*, the expected *iso*butyric acid [Found: (2) Ag, 64·3; (3) Ag, 63·3; (4) Ag, 63·8. Calc. for $C_2H_3O_2Ag$: Ag, 64·65%]. When portions of the volatile acidic oxidation products were reduced with magnesium and hydrochloric acid, the presence of formaldehyde could readily be demonstrated in the case of the hydrocarbon fractions (1) and (2).

Hydrocarbons from δ-Methyl-Δ^β-penten-δ-ol.—Preparation of δ-methyl-Δ^β-penten-δ-ol (XIV). Hydracetylacetone was prepared by Claisen's method (*Annalen*, 1899, **306**, 324) and dehydrated to ethylideneacetone by distillation with a trace of sulphuric acid (Kyriakides, *J. Amer. Chem. Soc.*, 1914, **36**, 534). Wohl and Maag's method (*Ber.*, 1910, **43**, 3284) was much less satisfactory.

The reaction of ethylideneacetone with methylmagnesium iodide was carried out at − 10°. The product, which distilled without dehydration, was collected at 35—43°/14 mm. (yield, 70%). There remained a liquid by-product, b. p. above 100° (some decomp.) The methylpentenol was rectified through a short column at atmospheric pressure. It was a colourless liquid, b. p. 122°/755 mm., 37°/13 mm., $d_{4°}^{17 \cdot 0°}$ 0·8319, $n_D^{17 \cdot 0°}$ 1·4285; $[R_L]_D$ 30·97 (calc., 30·97).

Dehydration. This was accomplished with either aniline hydrobromide or hydrobromic acid,

75% dehydration occurring in the first operation (see p. 1072) and 90% in two operations. The crude hydrocarbon was distilled. The fraction boiling below 80° was purified (p. 1072), and had finally b. p. 74—77°/751 mm. (Found: C, 87·7; H, 12·25. Calc. for C_6H_{10}: C, 87·7; H, 12·3%). It took up 2·0 mols. of hydrogen in presence of platinum, but its reaction with bromine (2 mols.) was still incomplete after 2 days. Yield, 65%.

Maleic anhydride derivative. When the hydrocarbon was mixed with maleic anhydride (1 equiv.) in benzene, some heat was evolved but no pronounced yellow colour developed. The crude derivative, allowed to form at room temperature for a week, dissolved readily in light petroleum, *leaving no appreciable residue of polymeric product.* On cooling, the solution was filled with a very characteristic thick and voluminous network of minute, silky, interlacing crystals. This addition product (3 : 5-dimethyl-Δ^4-tetrahydrophthalic anhydride), first reported by Diels and Alder as the derivative from $\alpha\gamma$-dimethylbutadiene, melted sharply at 58°. It showed a pronounced tendency, even when pure, to pass on long keeping into a sticky amorphous material of low m. p.; a similar change, resulting in the separation of a jelly-like material, occurred slowly in petroleum solutions of the derivative. This (apparently polymeric) change does not occur with the pure crystalline derivatives of other simple alkylbutadienes. The yield of total solid derivative, always higher than that from the hydrocarbons derived from β-methylpentane-βδ-diol and δ-methyl-Δ^α-penten-δ-ol (below), amounted to about 95%.

Fractionation. Intensive fractionation with an 18-inch column packed with glass beads showed that the hydrocarbon was heterogeneous. The following refractivities for fractions of different b. p. (at 774 mm. pressure) were observed: (1) b. p. 75·4—75·7°, $n_D^{13.5°}$ 1·4485; (2) b. p. 75·7—76·1°, $n_D^{13.5°}$ 1·4489; (3) b. p. 76·1—76·5°, $n_D^{13.5°}$ 1·4490; (4) b. p. 76·5—77·0°, $n_D^{13.5°}$ 1·4490; (5) b. p. 77·0—78·0°, $n_D^{13.5°}$ 1·4489. The chief portion, b. p. 74·8—75·2°, had $d_{4°}^{17.2°}$ 0·7195 and $n_D^{17.2°}$ 1·4466, whence $[R_L]_D$ 30·47; Σ 1·50.

Oxidation. From the high yield of the pure maleic anhydride derivative of $\alpha\gamma$-dimethylbutadiene obtained from the dehydration product of δ-methyl-Δ^β-penten-δ-ol it was clear that the amount of subsidiary dehydration products could not amount to more than about 5%. After oxidation of portions of the dehydration product in aqueous suspension with 3% permanganate solution at 0°, the products being worked up in the way described (p. 1072), the neutral distillate always gave a precipitate with 2 : 4-dinitrophenylhydrazine, m. p. *ca.* 126°. This proved on fractional crystallisation to be heterogeneous, consisting mainly of materials (partly unchanged reagent), m. p. 140° and above; indubitable acetone-2 : 4-dinitrophenylhydrazone could, however, not be isolated from it. On the other hand it gave oxalic acid in yields of 3—5%, and on this basis the hydrocarbon mixture is concluded to contain about 5% of αα-dimethylbutadiene. The acidic product of oxidation contained both acetic acid (Found for the silver salt: Ag, 64·6. Calc.: Ag, 64·65%) and formic acid (compare p. 1073) in good yield. In no case has pyruvic acid been obtained as an oxidation product of the $\alpha\gamma$-hydrocarbon, the degradation always proceeding further to give acetic acid.

Hydrocarbons from β-Methylpentane-βδ-diol.—This glycol (b. p. 95—97°/14 mm.) was prepared from diacetone alcohol by electrolytic reduction using lead electrodes (Kyriakides, *J. Amer. Chem. Soc.*, 1914, **36**, 994; Farmer, Lawrence, and Scott, J., 1930, 511).

Dehydration. In the presence of hydrobromic acid the diol underwent dehydration to the extent of 90% in two operations. The unsaturated alcohol observed by Kyriakides (see p. 1069) formed part of the distillate in the first operation: this was resubmitted to dehydration in the second operation. The hydrocarbon, purified in the usual way, boiled at 75—77°/775 mm., mainly at 76·0—76·4° (Found: C, 87·3; H, 12·5%). Yield, 50%.

When hydrogenated in presence of platinum, the hydrocarbon took up 2 mols. of hydrogen; towards bromine, however, its behaviour was similar to that of the hydrocarbon from δ-methyl-Δ^β-penten-δ-ol (above).

Maleic anhydride derivatives. The hydrocarbon, when kept for a week with the reagent in benzene, gave a good yield of the characteristic addition product from $\alpha\gamma$-dimethylbutadiene (m. p. 58°). A little polymeric material, however, separated from the benzene solution of the reactants while they were standing, and a further quantity of jelly-like substance of very sparing solubility in petrol was separated from the crude crystalline addition product on crystallisation from petroleum. The total solid addition product after the separation of unchanged maleic anhydride was about 85%.

Oxidation. The volatile neutral portion of the product obtained under the standard conditions of oxidation (see above) consisted partly of acetone (2 : 4-dinitrophenylhydrazone, m. p. 125°; mixed m. p. 125°) and partly of other compounds which gave with 2 : 4-dinitrophenylhydrazine a material melting above 160°. The volatile acidic portion of the oxidation product,

examined as above, contained both acetic acid, isolated as the silver salt (Found : Ag, 64·6%), and a not inconsiderable proportion of formic acid. The amount of oxalic acid (arising from the αα-hydrocarbon) formed in the oxidation was 0·07—0·1 mol. (estimated volumetrically).

Fractionation. The hydrocarbon, when distilled slowly at 774 mm. pressure under a good column, gave the following fractions : (1) b. p. 75·4—75·9°, $n_D^{13·5°}$ 1·4500; (2) b. p. 75·9—76·0°, $n_D^{13·5°}$ 1·4500; (3) b. p. 76·0—76·1°, $n_D^{13·5°}$ 1·4501; (4) b. p. 76·1—76·4°, $n_D^{13·5°}$ 1·4503; (5) b. p. 76·4—76·7°, $n_D^{13·5°}$ 1·4503. The bulk distilled at 75·0° ($d_{4°}^{17·2°}$ 0·7190, $n_D^{17·2°}$ 1·4484; whence $[R_L]_D$ 30·58; Σ 1·61).

Hydrocarbons from β-Methyl-Δ^β-penten-δ-ol.—Preparation of β-methyl-Δ^β-penten-δ-ol (XV). β-Methylcrotonaldehyde (β-methyl-Δ^α-butenaldehyde) was synthesised from *iso*amyl alcohol (Fischer, Ertel, and Löwenberg, *loc. cit.*). The conversion of the alcohol in turn into *iso*valeraldehyde (b. p. 91—92°), α-bromo-β-methylbutaldehyde, β-methyl-Δ^α-butenal diethyl acetal (b. p. 87—92°/15 mm.), and β-methylcrotonaldehyde (b. p. 129—134°/765 mm.) was carried out with substantially the same results, yields and boiling points as reported by Fischer and his collaborators (who give b. p. 132—133°/730 mm.).

The aldehyde was treated at − 10° with a small excess of methylmagnesium iodide, and the product worked up in the usual manner. The crude alcohol, obtained in 50% yield, distilled at 52—60°/20 mm. (136—142°/768 mm.), mainly at 55°/20 mm.; there was a considerable quantity of liquid residue. The *β-methyl-Δ^β-penten-δ-ol* required careful fractionation before it could be utilised for dehydration; the greater part, b. p. 137—138°, was a colourless liquid of pleasant but rather musty odour (Found : C, 72·0; H, 12·2. $C_6H_{12}O$ requires C, 71·9; H, 12·1%) and had $d_{4°}^{17·0°}$ 0·8448 and $n_D^{17·0°}$ 1·4318, whence $[R_L]_D$ 30·72 (calc., 30·97).

Hydrogenation showed that the alcohol contained 1·0 double bond per molecule. Oxidation with permanganate at 0° in the usual way gave a copious quantity of acetone (2 : 4-dinitrophenylhydrazone, m. p. 125°; mixed m. p. 125°), and much acetic acid (*p*-bromophenacyl ester, m. p. 84·5°; mixed m. p. 84·5°). Some lactic acid survived in the crude oxidation product as demonstrated by numerous qualitative tests, but the bulk of this primary oxidation product had become oxidised to acetic acid.

Dehydration. The alcohol was dehydrated smoothly and almost completely when twice distilled with small portions of hydrobromic acid. The hydrocarbon, after the usual purification, boiled at 75—80°; almost the whole, however, passed over, on redistillation, at 77—78°/760 mm. ($d_{4°}^{18·2°}$ 0·7163, $n_D^{18·2°}$ 1·4396; $[R_L]_D$ 30·18; Σ 1·21). Several samples of the hydrocarbon arising from different fractions of the parent alcohol gave concordant values for boiling point, density, refractive index, and molecular refraction.

Maleic anhydride derivatives. The product formed as in preceding examples was almost entirely a white, wax-like polymeride, but when removal of the solvent was complete, it was found to be coated with minute feathery tufts of crystalline material identical in appearance with the very characteristic derivative of αγ-dimethylbutadiene. The amount of the latter, however, was so small that it could not be separated by solvent action from the polymeric material, which was itself slightly soluble in hydrocarbon solvents; no satisfactory melting point of the crystalline derivative could therefore be obtained.

Oxidation. Under the usual conditions of oxidation the hydrocarbon yielded much formic acid, oxalic acid, and acetone (2 : 4-dinitrophenylhydrazone, m. p. 124—125°; mixed m. p. 124—125°). The formic acid contained an appreciable proportion of acetic acid, since silver acetate was isolated without difficulty (Found : Ag, 64·2%).

Attempted Dehydration of δ-Methyl-Δ^α-penten-γ-ol (XVI).—The procedure described by Bouis (*Ann. Chim.*, 1928, **9**, 402) for the preparation of this alcohol from acraldehyde and *iso*propylmagnesium bromide, and also several modifications thereof in which the reactants were kept very cold during addition, gave yields of 9% or less. Neither *iso*propyl chloride nor the corresponding iodide proved to be satisfactory substitutes for the bromide. The following procedure, which gave a 20% yield, was the best one discovered.

*iso*Propylmagnesium bromide (1·1 mols.), dissolved in ether (800 c.c.), was treated while still warm with freshly distilled acraldehyde (1 mol.) in ether at such a rate as to maintain gentle ebullition. The ethereal solution, when reaction had ceased, was clear and colourless. The product, after hydrolysis with water, yielded the required alcohol, boiling fairly constantly at 43°/21 mm.; after two further distillations the alcohol had b. p. 124—125°/753 mm., $d_{4°}^{15·6°}$ 0·8412, $n_D^{15·6°}$ 1·4316; $[R_L]_D$ 30·83 (calc., 30·97). The residual liquid was a colourless pleasant-smelling oil, b. p. about 150°/21 mm., leaving a highly viscous residue, undistillable at 10—20 mm. pressure.

The alcohol absorbed 1·01 mols. of hydrogen in presence of platinum and gave on oxidation

with permanganate in the usual way much formic acid, a little oxalic acid (0·8 mol.), and unidentified material.

Behaviour with hydrobromic acid and with iodine. The clear orange solution obtained when 1 c.c. of hydrobromic acid was added to the pure alcohol was heated, dehydration apparently occurring since water distilled; this, however, was only that which had been introduced in the hydrobromic acid, and immediately it had passed over the temperature of the distillate rose to the b. p. of the alcohol. No decomposition could be induced by adding further quantities of hydrogen bromide, and no hydrocarbon could be detected in the distillate.

When iodine replaced hydrobromic acid as catalyst, no water at all was evolved and dehydration could not be induced.

Dehydration of Dimethylallylcarbinol with Phenylcarbimide.—The carbinol was heated with phenylcarbimide at 100° for 48 hours. A clear brown solution resulted from which a mixture of hydrocarbon and reagent distilled on heating, leaving diphenylurea in the flask. The impure hydrocarbon was treated with alcohol to remove the reagent, and precipitated by addition of water. The precipitated hydrocarbon, after the customary thorough washing with water, was obtained in 60% yield. On treatment with sodium a vigorous reaction ensued, some constituent being converted into a white solid. The residual hydrocarbon boiled at 60—75° and could be separated by fractional distillation into a non-conjugated and a conjugated portion. When the conjugated portion was oxidised, acetone and formic acid were the only volatile products found; when it was treated with maleic anhydride, much polymeric material was obtained but no crystalline derivative of αγ-dimethylbutadiene could be isolated.

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Imperial College, London, S.W. 7. [*Received, September 25th,* 1936.]

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224. *Steroids and Related Compounds. Part I. Isomeric Cholestenediols.*

By Vladimir A. Petrow.

The dehydration of various derivatives of cholestane-3 : 5 : 6-triol to the corresponding Δ^4-cholestene-3 : 6-diols has been carried out. The further dehydration of these compounds to $\Delta^{4:6}$-cholestadien-3-ol has been attempted, but definite products could not be isolated.

Dehalogenation of cholesteryl ester dibromides with various reagents has been examined as another possible method of preparing $\Delta^{4:6}$-cholestadien-3-ol. *cis*-Δ^5-Cholestene-3 : 4-diol was isolated in each case from the products.

"Monobromocholesteryl benzoate" has been identified as 5 : 5′-dibromo-3 : 3′-dibenzoyloxy-6 : 6′-dicholestanyl. Its dehalogenation has been examined.

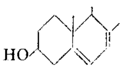
The method at present available for the production of 7 : 8-dehydrocholesterol (I) is the dehydration of Δ^5-cholestene-3 : 7-diol (Windaus, Lettré, and Schenck, *Annalen*, 1935, **520**, 98). As an alternative route, the dehydration of cholestane-3 : 5 : 6-triol derivatives and the dehalogenation of cholesteryl ester dibromides have been studied.

Westphalen (*Ber.*, 1915, **48**, 1064) dehydrated cholestane-3 : 5 : 6-triol diacetate (Pickard and Yates, J., 1908, **93**, 1678; Westphalen, *loc. cit.*) to 3 : 6-diacetoxy-Δ^4-cholestene (II). The removal of the C_6-hydroxyl group from this compound should furnish $\Delta^{4:6}$-cholestadien-3-ol (III), which might be expected, by analogy with the production of dehydroergosterol from ergostadientriol (I) (Windaus and Lüttringhaus, *Annalen*, 1930, **481**, 119), to isomerise readily to the desired 7 : 8-dehydrocholesterol (I).

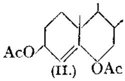
The diacetate (II) distilled unchanged on heating. The *dibenzoate* was stable up to about 290°/5 mm.; resinification then occurred.

Since cholesterilene can be obtained in good yield by the dry distillation of cholesteryl acetate under slightly reduced pressure (unpublished result; cf. Heilbron and Sexton, J., 1928, **347**), it seemed probable that (III) might be obtained from *3-benzoyloxy-6-acetoxy-Δ^4-cholestene* (IV) by distillation: this compound decomposed above 280°/5 mm., but

benzoic acid was evolved, *i.e.*, preferential removal of the C_3 hydroxyl group took place. 6-*Acetoxy-3-methoxy-Δ⁴-cholestene* was stable and distilled unchanged.



(I.)



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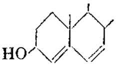
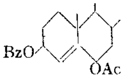
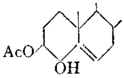


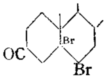
(III.)



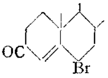
(IV.)



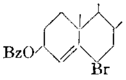
(V.)



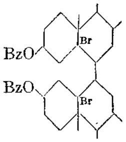
(VI.)



(VII.)



(VIII.)



(IX.)

The removal of two molecules of hydrogen bromide from cholesterol dibromide suggested another method of preparing (III). Treatment of cholesteryl acetate dibromide with potassium acetate in absolute alcohol gave cholesteryl acetate (cf. Urushibara and Ando, *Bull. Chem. Soc. Japan*, 1936, **11**, 434) together with cis-*4-hydroxy-3-acetoxy-Δ⁵-cholestene* (V), m. p. 177°. The identity of the latter was established by acetylation; the *cis*-3 : 4-diacetoxy-Δ⁵-cholestene obtained, m. p. 167°, was identical with the compound described by Rosenheim and Starling (this vol., p. 377) and by Butenandt and Hausmann (*Ber.*, 1937, **70**, 1154) and gave *cis*-Δ⁵-cholestene-3 : 4-diol on hydrolysis. Treatment of cholesteryl acetate dibromide with sodium acetate in aqueous-alcoholic solution gave similar results.

Treatment of cholesteryl acetate dibromide with pyridine gave cholesteryl acetate in nearly quantitative yield; with silver nitrate in pyridine solution, followed by acetylation of the product, *cis*-3 : 4-diacetoxy-Δ⁵-cholestene was obtained in a yield of about 20%.

Bromination of cholesteryl benzoate gives a substance that is apparently a monobromo-substitution product, together with the normal cholesteryl benzoate dibromide in small yield (Dorée and Orange, J., 1916, **109**, 53). By analogy with the spontaneous conversion of Δ⁵-cholesten-3-one dibromide (VI) into 6-bromo-Δ⁴-cholesten-3-one (VII) (Dane, Weg, and Schulte, *Z. physiol. Chem.*, 1936, **245**, 81) it seemed probable that the "monobromocholesteryl benzoate" was in reality 6-bromo-3-benzoyloxy-Δ⁴-cholestene (VIII). The compound, however, was saturated (tetranitromethane, bromine) and had a molecular weight of the order of 1000. It must therefore be a dibromodihydrodicholesteryl derivative. Atomic-scale models show that it is best formulated as 5 : 5′-dibromo-3 : 3′-dibenzoyloxy-6 : 6′-dicholestanyl (IX) rather than the 6 : 6′-dibromo-5 : 5′-dicholestanyl compound. On dehalogenation with pyridine it gave cholesteryl benzoate in quantitative yield, and with silver nitrate in pyridine solution a product was obtained from which, after hydrolysis, both cholesterol and *cis*-Δ⁵-cholestene-3 : 4-diol were isolated. Cholesteryl benzoate dibromide likewise gave the *cis*-diol on treatment either with potassium acetate in alcohol or with silver nitrate in pyridine, so the compound (IX) evidently reacts in solution as an equimolecular mixture of cholesteryl benzoate and cholesteryl benzoate dibromide.

Debromination of cholesteryl ester dibromides by the above methods thus takes the following course : (i) elimination of the bromine atom attached to C_5 takes place with the formation of a 6-bromo-3-hydroxy-Δ⁴-cholestene derivative, and (ii) an intramolecular rearrangement to *cis*-4-bromo-3-hydroxy-Δ⁵-cholestene occurs, followed by hydrolysis to *cis*-Δ⁵-cholestene-3- : 4-diol.

Removal of two molecules of hydrogen bromide from Δ⁵-cholesten-3-one dibromide

(VI) takes a normal course, yielding first the bromo-ketone (VII) and finally $\Delta^{4:6}$-cholestadien-3-one (Dane *et al.*, *loc. cit.*). The tendency of the double bond to retain an $\alpha\beta$-position with respect to the ketonic group in this compound evidently prevents the allene change taking place. The preferential formation of the *cis*-diol from cholesteryl ester dibromides, moreover, is in agreement with the observation of Butenandt (*Ber.*, **1936**, **69**, 2289) that the bromine atoms in cholesterol dibromide have a *cis*-configuration with respect to the hydroxyl group and with the angular methyl group at C_{10}.

EXPERIMENTAL.

Microanalyses by Dr. G. Weiler are marked with an asterisk. The optical rotations were measured in chloroform solution in a 2 dm. tube.

Cholestane-3 : 5 : 6-*triol Diacetate*.—The following modified procedure gives a better yield than that of Pickard and Yates (*loc. cit.*) : Powdered cholesteryl acetate (5 g.) in glacial acetic acid (250 ml.) is treated with Merck's perhydrol (5 ml.) at room temperature for 4 days, the mixture being shaken at intervals. Water (250 ml.) is added and the precipitated solids are acetylated and purified from alcohol. Yield, 50—60%.

3 : 6-*Dibenzoyloxy*-Δ^4-*cholestene*.—25 G. of cholestanetriol diacetate in 300 ml. of acetic anhydride were treated with a few drops of concentrated sulphuric acid for 15 minutes on the water-bath. After hydrolysis the product was dissolved in 250 ml. of pyridine and heated with 25 ml. of benzoyl chloride for 1 hour on the water-bath. After extraction with 300 ml. of alcohol and purification from acetone, 3 : 6-*dibenzoyloxy*-Δ^4-*cholestene* formed silky needles, sintering at 163·5—164·5° and clearing at 182° (Found* : C, 80·5; H, 8·7. $C_{41}H_{54}O_4$ requires C, 80·7 ; H, 8·8%).

Δ^4-Cholestene-3 : 6-diol, obtained by hydrolysis of the dibenzoate, formed silky needles, m. p. 110·5—111·5°, from aqueous methyl alcohol (diacetate, m. p. 125° ; Westphalen, *loc. cit.*). It gave a red colour with trichloroacetic acid on standing.

5-*Hydroxy*-3-*benzoyloxy*-6-*acetoxycholestane*.—2 G. of finely powdered cholesteryl benzoate in 50 ml. of glacial acetic acid were treated with 2 ml. of perhydrol for 1 hour on the water-bath. Water (50 ml.) was added, and the mixture kept overnight. The precipitated solids, after acetylation, were purified from alcohol and from light petroleum. 5-*Hydroxy*-3-*benzoyloxy*-6-*acetoxycholestane* formed flat needles, m. p. 162·5—163·5°, $[\alpha]_D$ −23·8° (c = 1·68) (Found : C, 76·3; H, 9·6. $C_{36}H_{54}O_5$ requires C, 76·5; H, 9·5%). Yield, 40—50%. On saponification it gave cholestanetriol, identified by m. p. and mixed m. p. with an authentic specimen.

3-*Benzoyloxy*-6-*acetoxy*-Δ^4-*cholestene*.—5-Hydroxy-3-benzoyloxy-6-acetoxycholestane in excess of acetic anhydride was treated with a trace of concentrated sulphuric acid for 15 minutes on the water-bath. The product was poured into water and purified from methyl alcohol–ether. 3-*Benzoyloxy*-6-*acetoxy*-Δ^4-*cholestene* separated from methyl alcohol as a flocculent mass, m. p. 138·5° (Found* : C, 78·1; H, 9·4. $C_{36}H_{52}O_4$ requires C, 78·8; H, 9·5%). On saponification it gave Δ^4-cholestene-3 : 6-diol, identified by m. p., mixed m. p., and conversion into the diacetate. It gave a yellow colour with tetranitromethane.

5 : 6-*Dihydroxy*-3-*methoxycholestane*.—25 G. of cholesteryl methyl ether, m. p. 84° (Stoll, *Z. physiol. Chem.*, 1932, **207**, 147), in 200 ml. of glacial acetic acid were treated with 25 ml. of perhydrol, with mechanical stirring, for 20 minutes on the water-bath. Water (300 ml.) was added, and the mixture kept overnight. The precipitated solids, after saponification, were dissolved in 100 ml. of light petroleum and after 12 hours the deposited crystals were removed, extracted with 50 ml. of light petroleum, and recrystallised from aqueous alcohol. 5 : 6-*Dihydroxy*-3-*methoxycholestane* formed flat plates, m. p. 154°, $[\alpha]_D$ −4·8° (c = 3·1) (Found* : C, 77·8; H, 11·5. $C_{28}H_{50}O_3$ requires C, 77·4; H, 11·5%), soluble in most organic solvents except benzene and light petroleum. Yield, 50—60%.

5-*Hydroxy*-6-*benzoyloxy*-3-*methoxycholestane*.—2 G. of 5 : 6-dihydroxy-3-methoxycholestane in 30 ml. of pyridine were treated with 2 ml. of benzoyl chloride for 24 hours at room temperature. The product was poured into water, and the precipitated solids crystallised from alcohol. 5-*Hydroxy*-6-*benzoyloxy*-3-*methoxycholestane* formed silky needles, m. p. 96·5—97·5°, $[\alpha]_D$ −33·1° (c = 2·42) (Found* : C, 77·4; H, 10·2. $C_{35}H_{54}O_4$ requires C, 78·0; H, 10·0%), moderately soluble in methyl and ethyl alcohols and readily soluble in ethyl acetate and light petroleum. Dehydration of this compound to the corresponding Δ^4-cholestene derivative with concentrated sulphuric acid in acetic anhydride solution was not successful, intractable gums being obtained.

5-*Hydroxy*-6-*acetoxy*-3-*methoxycholestane*.—2 G. of 5 : 6-dihydroxy-3-methoxycholestane in 8 ml. of acetic anhydride were heated for 1 hour on the water-bath. The product, on crystallisa-

tion from alcohol, gave white plates of *5-hydroxy-6-acetoxy-3-methoxycholestane*, m. p. 118·5—119·5°, $[\alpha]_D$ −30·1° (c = 2·57) (Found*: C, 75·4; H, 10·2. $C_{30}H_{52}O_4$ requires C, 75·6; H, 10·9%).

6-Acetoxy-3-methoxy-Δ⁴-cholestene.—0·2 G. of 5-hydroxy-6-acetoxy-3-methoxycholestane was heated for 15 minutes with 20 ml. of acetic anhydride containing a trace of concentrated sulphuric acid. The product was isolated in the usual way and dissolved in a little ether, and hot methyl alcohol added until a faint turbidity appeared. After standing overnight, the crystalline deposit was filtered off and purified from ether–methyl alcohol. *6-Acetoxy-3-methoxy-Δ^4-cholestene* formed flat needles, m. p. 121·5—122·5°, $[\alpha]_D$ +166·6° (c = 0·15) (Found*: C, 78·3; H, 10·9. $C_{30}H_{50}O_3$ requires C, 78·6; H, 10·9%), moderately soluble in the usual organic solvents. The compound gave a yellow colour with tetranitromethane. In admixture with 5-hydroxy-6-acetoxy-3-methoxycholestane a m. p. depression of 20° was obtained. The compound distilled unchanged in a vacuum.

Dehalogenation of Cholesteryl Acetate Dibromide.—(a) *With potassium acetate in absolute alcohol*. 10 G. of cholesteryl acetate dibromide (m. p. 118°), 20 g. of anhydrous potassium acetate, and 400 ml. of absolute alcohol were refluxed for 48 hours. The product was evaporated to dryness under reduced pressure, and the residue extracted with light petroleum. On concentration, crystals of cis-*4-hydroxy-3-acetoxy-Δ^5-cholestene* were deposited which, after purification from light petroleum, had m. p. 176—177°, $[\alpha]$ −84·4° (c = 2·08) (Found*: C, 78·6; H, 10·8. $C_{29}H_{48}O_3$ requires C, 78·4; H, 10·8%). Yield, 10—15%. The product gave no colour with tetranitromethane, a deep blue trichloroacetic acid test (Rosenheim), and a purple antimony trichloride reaction. Acetylation, followed by crystallisation from acetic acid, gave needles of *cis*-3 : 4-diacetoxy-Δ^5-cholestene, m. p. 168—169°, $[\alpha]_D$ −93·6° (c = 3·0) (Found*: C, 76·4; H, 10·6. Calc. for $C_{31}H_{50}O_4$: C, 76·5; H, 10·4%), alone or in admixture with an authentic specimen kindly supplied by Dr. O. Rosenheim. Its identity was further confirmed by hydrolysis, *cis*-Δ^5-cholestene-3 : 4-diol being obtained, m. p. 176° (Found*: C, 80·3; H, 11·6. Calc. for $C_{27}H_{46}O_2$: C, 80·5; H, 11·5%); this was dehydrated by alcoholic hydrochloric acid to coprostenone (semicarbazone, m. p. 236—237°; 2 : 4-dinitrophenylhydrazone, m. p. 236—237°).

The light petroleum mother-liquors from the above gave, on further concentration, a microcrystalline deposit of cholesteryl acetate.

(b) *With sodium acetate in aqueous alcohol*. 6 G. of cholesteryl acetate dibromide were refluxed for 3 hours with a solution of 20 g. of sodium acetate in 200 ml. of 90% aqueous alcohol. The product was extracted with ether and formed a pale yellow gum. It was acetylated with 25 ml. of acetic anhydride for 30 minutes on the water-bath. The solution on cooling deposited a small quantity of gummy crystals, which were purified from alcohol and from glacial acetic acid and identified as the diacetate of the *cis*-diol by m. p. and mixed m. p.

(c) *With silver nitrate in pyridine solution*. To a solution of 10 g. of silver nitrate in 200 ml. of pyridine were added, in small portions with shaking, 10 g. of cholesteryl acetate dibromide. The mixture was warmed gently until solution was complete and left overnight at room temperature. The product was extracted with ether and acetylated (50 ml. of acetic anhydride for 1 hour on the water-bath). On cooling, crystals were deposited which, after purification from glacial acetic acid, formed needles, m. p. 166·5°, $[\alpha]_D$ −87·5° (c = 0·4) (Found: C, 75·9; H, 9·9. Calc. for $C_{31}H_{50}O_4$: C, 76·5; H, 10·4%), identified with *cis*-3 : 4-diacetoxy-Δ^5-cholestene by mixed m. p., by saponification to the diol, m. p. 174—175° (Found*: C, 80·6; H, 11·5. Calc. for $C_{27}H_{46}O_2$: C, 80·5; H, 11·5%), and by dehydration to coprostenone. Yield, 2·3 g.

5 : 5′-*Dibromo*-3 : 3′-*dibenzoyloxy*-6 : 6′-*dicholestanyl*.—The following procedure was adopted (cf. Dorée and Orange, *loc. cit.*): 84 Ml. of a 27% solution of bromine in carbon disulphide were added dropwise to a solution of 63 g. of cholesteryl benzoate in 400 ml. of carbon disulphide at 0°, the mixture being mechanically stirred. The solvent was then removed under reduced pressure, the yellow gummy residue taken up in 100 ml. of chloroform, absolute alcohol added until a faint turbidity appeared, and the mixture left overnight to crystallise. The product, purified from acetone, formed prisms, m. p. 140°. Molecular weight 1060 (0·5 g. in 53 ml. of benzene raised the b. p. by 0·029°). From the acetone mother-liquor a small quantity of cholesteryl benzoate dibromide was isolated, m. p. 167°.

Dehalogenation of the Dibromodicholestanyl Compound.—5 G. of the compound were added to a 6% solution of silver nitrate in pyridine. After standing overnight at room temperature, the liquid was poured into water and extracted with ether. The product was evaporated to dryness and dissolved in a little pyridine, and alcohol added. The crystalline deposit, after crystallisation from acetone–methyl alcohol, was extracted with a large bulk of boiling alcohol

and filtered hot. The insoluble residue consisted of cholesteryl benzoate. The filtrate, on cooling, deposited flat needles, m. p. 133—134° (Found* : C, 81·7; H, 10·0%), from which, by saponification and crystallisation from light petroleum, the *cis*-diol was obtained, m. p. 176° (Found : C, 80·3; H, 11·5. Calc. for $C_{27}H_{46}O_2$: C, 80·5; H, 11·5%), identified by mixed m. p. and by conversion into the diacetate, m. p. 167°.

Dehalogenation of Cholesteryl Benzoate Dibromide.—(a) *With potassium acetate in alcohol.* 1·0 G. of cholesteryl benzoate dibromide in 40 ml. of acetone was added to a suspension of excess of anhydrous potassium acetate in 40 ml. of absolute alcohol, and the mixture refluxed for 3 hours. The product was evaporated to dryness under reduced pressure, and the residue extracted with ether. On addition of alcohol, crystals of cholesteryl benzoate were obtained. The mother-liquor deposited a further crop of material. This was hydrolysed, and the product extracted once with a small quantity of light petroleum and refluxed for 1 hour with 2 ml. of acetic anhydride. Crystals were deposited on cooling, which, after purification from alcohol, gave *cis*-3 : 4-diacetoxy-Δ^5-cholestene, m. p. 168° (Found : C, 76·2; H, 10·6. Calc. for $C_{31}H_{50}O_4$: C, 76·5; H, 10·4%), identified by mixed m. p.

(b) *Dehalogenation with silver nitrate in pyridine.* 0·5 G. of the dibromide was added to a solution of 0·5 g. of silver nitrate in 10 ml. of pyridine, and the mixture heated on a water-bath for 15 minutes. The liquid was poured into water and extracted with ether. The resulting oil was hydrolysed, and the product acetylated by heating for 1 hour on the water-bath with 2 ml. of acetic anhydride; crystals were deposited on cooling, identified as before with *cis*-3 : 4-diacetoxy-Δ^5-cholestene.

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225. *Some Observations on Colloidal Solutions of Silver and Copper.*

By H. FREUNDLICH and DORA STEINER.

(1) NEEDING silver sols of various particle sizes, free from organic substances, we did not use dextrin for reduction (Wiegel, *Kolloid-Z.*, 1929, **47**, 323; 1930, **51**, 112; **53**, 96; *Z. physikal. Chem.*, 1929, *A*, **143**, 81), but obtained a very clear, yellow nuclear sol by reduction of silver oxide in ammoniacal solution with hydrazine hydrate. A stock silver solution was prepared by dissolving the freshly precipitated oxide in aqueous ammonia (Ag : NH_3 = *ca.* 1 : 4), and diluting this to 0·01*M* with regard to silver. For preparation of the sol, 10 c.c. of this solution were diluted to 100 c.c. and reduced by addition of 100 c.c. of water containing 2 c.c. of a stock 0·1% hydrazine hydrate solution (B.D.H.).

From this nuclear sol, coarser, but fairly homodisperse sols were prepared by treating suitable amounts of the sol with hydrogen peroxide, as in Wiegel's method. Some of the silver particles are dissolved in the peroxide, and this silver is deposited upon the remaining nuclei. The colour changes with increasing particle size in the following series : yellow, orange, red, violet, deep blue, pale blue. If the number of nuclei is very small, they grow so much at the expense of the dissolved silver that visible flakes are formed, mostly floating on the liquid. The colour series mentioned is similar to that observed when using a nuclear sol prepared with dextrin or with a solution of phosphorus in ether. There are, however, a few minor differences which are not readily explained owing to insufficient knowledge of the rate of crystallisation of silver in solutions of this kind and of the decomposition of hydrogen peroxide in presence of ammonia.

The foregoing results were obtained when using ordinary distilled water, but if the stock solutions were diluted with conductivity water, good nuclear sols were not obtained. They were decidedly coarser, markedly opaque, especially in reflected light, and less homodisperse : if used as a nuclear sol, the sols containing larger particles did not show the clear, strong colour distinctive of homodisperse sols. Now it was known that the distilled water contained copper to the extent of 0·3—0·4 mg. per litre (as determined colorimetrically with potassium ferrocyanide), so a nuclear sol was prepared by using a solution of conductivity water containing 0·002 millimol. of copper sulphate (somewhat less than the amount in distilled water); a clear, homodisperse sol was formed, exactly like one prepared with distilled water. Hence the presence of copper is obviously the factor favouring the formation of a transparent, homodisperse sol, when using distilled water.

There is an optimum in the concentration of copper sulphate between 0·006 and 0·007

millimol. per litre. This amount of copper is not the most suitable for all silver concentrations: for much smaller concentrations, the amount of copper present in the distilled water may be large enough to cause coagulation. At higher copper sulphate concentrations, markedly above 0·015 millimol./litre, flocculation becomes evident, the colour of the sol being very dark in reflected, and brown in transmitted, light.

The presence of small amounts of copper is essential to the formation of good silver mirrors on glass; *e.g.*, by reducing alkaline silver solution with glucose. According to Kohlschütter and Fischmann (*Annalen*, 1912, **387**, 86), the formation of such mirrors depends on a number of factors; among others, the silver must be precipitated in a homodisperse, colloidal state, such a precipitation being favoured by small amounts of copper. Our results confirm this statement. Those authors found that small, but somewhat larger amounts of lead and zinc act in the same way as copper in improving the deposition of mirrors. Correspondingly, we found that the preparation of a nuclear silver sol with conductivity water is improved by addition of small amounts of lead nitrate or zinc sulphate. Mirror and sol formation are also similar in that in both cases the favourable influence of foreign metals is confined to a narrow range of concentrations: slightly larger amounts cause coagulation of the silver particles; black silver is formed instead of a mirror, and the sol changes its colour owing to coagulation.

The mechanism of the action of these metals is not known with certainty. Perhaps highly disperse particles of the metal oxides (or hydroxides) are present and are able to act as nuclei or are instrumental in distributing the primary silver nuclei in a similar dispersion (" orientating action " of Kohlschütter).

Zsigmondy and his collaborators (*e.g.*, Zsigmondy and Thiessen, " Das kolloide Gold," Leipzig, 1925; Hiege, *Z. anorg. Chem.*, 1915, **91**, 145; Reitstötter, *Kolloidchem. Beih.*, 1917, **9**, 222) investigated the influence of foreign substances upon the formation of gold sols. To a certain extent they were able to distinguish between substances which change the rate of formation of nuclei (a) and others which change the rate of crystallisation (b); *e.g.*, ammonia, hydrazine sulphate, ferro- and ferri-cyanide ions strongly reduce (a) without influencing (b); when present, they therefore only allow the preparation of more or less coarse sols. These substances have a similar effect on the preparation of silver sols as described above. Addition of small amounts of potassium ferro-, ferri-, or nickelo-cyanide or of an excess of ammonia to conductivity water prevents the formation of yellow, highly disperse sols. At higher concentrations (*e.g.*, 0·15 millimol./litre of the nickelocyanide) the formation of silver particles is delayed for many hours or entirely inhibited. Obviously also, hydrazine, as with gold sols, is not a reducing agent which naturally would favour the formation of highly disperse silver sols; it needs the presence of substances like copper, etc., to give satisfactory results.

Potassium cyanide acts like the complex cyanides. The ferrocyanide is able to dissolve colloidal silver, as reported by Beutel and Kutzlnigg (*Monatsh.*, 1929, **51**, 369) and confirmed by us. This might suggest that the cyanide ion acts directly by rapidly and preferentially dissolving the very small silver nuclei, the larger ones surviving and growing at the expense of the dissolved silver. It might be objected that complex ions such as ferrocyanide are very stable: no ferrous ion can be detected in ferrocyanide solutions by the polarographic method (Sanigar, *Rec. trav. chim.*, 1925, **44**, 549; Emelianova, *ibid.*, p. 528). This result does not rule out the possibility that cyanide ion may be split off, leaving some other complex ion, and hitherto no extensive investigation on the concentration of cyanide ion in solutions of complex cyanides appears to have been carried out.

An excess of ammonia might act like cyanides, dissolving the small nuclei preferentially.

Phosphorus in ether is a reducing agent not only for gold but also for silver, causing a very rapid formation of metal nuclei and hence of most highly disperse sols. Those of silver are obtained also when conductivity water is used, *i.e.*, in absence of copper, or with an excess of ammonia. Sols prepared by passing phosphine through an ammoniacal solution of silver oxide (M/1000 with regard to Ag) are highly disperse, like those made with phosphorus. They may be used as nuclear sols in presence of an excess of ammonia, etc.

These experiments were confirmed by observations with the cardioid-ultramicroscope, as is shown by the following summary.

Silver sol prepared with:	Observation.
Phosphorus in ether	No particles visible
N_2H_4,H_2O in distilled water (Cu present)	Very small particles; a few larger ones
,, in conductivity water (Cu absent)	Many larger particles, also some smaller ones
,, and excess of NH_3	Mainly large particles
,, and a small amount of $K_4Fe(CN)_6$	Mainly large particles

(2) Red, fairly stable, aqueous sols of copper, not containing large amounts of a protective substance, have only occasionally been described (Gutbier, *Z. anorg. Chem.*, 1902, **32**, 355; Meyer, *ibid.*, 1903, **34**, 60; cf. Sauer and Steiner, *Kolloid-Z.*, 1935, **72**, 35). When an ammoniacal solution of copper oxide was reduced with hydrazine hydrate, red copper sols were sometimes obtained, but it was not possible to find conditions regularly yielding this result. The sols generally obtained were rather coarse, bluish-green in transmitted and copper-red in reflected light, and distinctly opaque. Since phosphorus in ether produces highly disperse gold and silver sols, we hoped it would be equally effective for preparing highly disperse copper sols, but mere addition of phosphorus in ether to an ammoniacal copper solution did not give satisfactory results. At room temperature, the liquid became dark only when the phosphorus concentration was large; on heating, a brownish-black colloidal solution was formed over a wide range of concentrations. This appears to be a copper phosphide sol: its formation is favoured by an excess of phosphorus and it is easily oxidised by air. The tendency of copper to form phosphides is known to be greater than that of gold and silver (cf. Gmelin–Friedheim, 1909, Vol. 5, I, 958), and the rate of this reaction seems to surpass all others. The successive action of hydrazine hydrate and phosphorus, however, produces highly disperse, transparent, beautifully red copper sols, looking like copper ruby glass, the results being reproducible. 3 C.c. of a solution of copper oxide in aqueous ammonia ($Cu = M/100$; $NH_3 = 1{\cdot}0M$) are diluted with 10 c.c. of water and heated to boiling; 3 c.c. of hydrazine hydrate (0·5%) are added, and immediately afterwards 1·5 c.c. of a solution of phosphorus in ether (the saturated solution diluted to 10 times its volume). On addition of the hydrazine hydrate the bluish liquid turns colourless (reduction to univalent copper), and on addition of the phosphorus it becomes first yellow and then red.

This sol is amicronic, no particles being seen under the cardioid-ultramicroscope, and they mainly consist of metallic copper. This was proved by an *X*-ray analysis, for which we are very indebted to Mr. H. Terrey. The sol, containing 2·5 millimols. (*i.e.*, 0·16 g. Cu/l.), was just coagulated with lithium nitrate, centrifuged for a short time, the excess of water poured off, and the sediment, in presence of some water, sealed into a glass capillary. The Debye–Scherrer diagram was that of metallic copper. The particles of this sol are negatively charged, as shown by electrophoresis.

The mechanism of the formation of this sol is complicated. First, a highly disperse sol of some other substance is formed whose particles appear to act as nuclei for the copper sol: the liquid turns yellow, at room temperature, if the ammoniacal solution of bivalent (or also of univalent) copper is mixed with hydrazine hydrate and phosphorus solution; on heating it becomes darker. The dark brown solution, appearing on heating with an excess of phosphorus, turns yellow on shaking or in course of time. The same yellow colloidal solution is produced, if phosphine is passed through an ammoniacal copper solution to which some hydrazine hydrate has been added, or if the latter substance is poured on the ammoniacal solution after it has been treated for a very short time with phosphine. If the treatment with phosphine is too prolonged, a black sol is formed, which turns yellow again when oxidised by being shaken with air and then mixed with hydrazine hydrate. The formation of this yellow sol also always precedes that of a red copper sol on heating according to the standard method described above.

This primary substance might be a very highly disperse copper phosphide. This assumption, however, is not free from objection: it would mean that the copper has to be deposited on the nuclei of the phosphide, because the latter is not readily reduced by hydrazine hydrate; if a brownish-black sol of the phosphide is produced by adding an excess of phosphorus in ether, it cannot be reduced to a red sol, even with an excess of hydrazine hydrate. Moreover, if phosphine acts upon an ammoniacal copper solution, heated to boiling and containing hydrazine hydrate, only a transitory formation of a red sol is observed, the liquid finally becoming black (copper phosphide). Also it is not clear why the formation of the primary, yellowish sol appears to proceed particularly easily with phosphine. The possibility that the primary nuclei consist of some other copper compound cannot yet be excluded.

These experiments agree with v. Weimarn's conception (*Kolloid-Z.*, 1929, **47**, 231) that the preparation of highly disperse metal sols need not depend mainly on the rate of formation of metal nuclei from dissolved substances; nuclei of an intermediate, insoluble compound may be produced which are particularly liable to form highly disperse sols. The nuclei of this intermediate substance may be reduced to the metal or be coated with it.

When hydrazine hydrate acts upon an ammoniacal copper solution in absence of phosphorus, an excess of ammonia is inimical to the production of highly disperse copper sols. As with silver, the ammonia may dissolve the very small metal nuclei formed. Perhaps pre-formed nuclei are again essential; particles of copper oxide (or hydroxide), present from the start,

may act in this way, either as such or after having been reduced to copper. They, too, would only be in the solution when the excess of ammonia is small, *i.e.*, when the copper–ammonia complex is dissociated to a sufficiently high degree. This colloidal oxide is most probably positively charged, whereas the copper particles are negative; hence there is always the danger that the oxide will coagulate the freshly formed copper sol, thus preventing or impeding the production of a highly disperse sol. There is probably a narrow range in the concentration of the copper–ammonia complex favourable for producing the sol. The amount and dispersion of the copper oxide are not alone responsible; other factors influencing the rate of reduction and coagulation must also be taken into account and are not easily kept constant. In agreement with this conception, the transitory formation of a red, clear sol is frequently observed; the final sols are, however, generally coarser, being copper-red in reflected and bluish-green in transmitted light. Their particles also consist of metallic copper, as proved by *X*-ray analysis.

Amicronic red sols are probably produced so much more easily in presence of phosphorus because the primary nuclei formed there, *i.e.*, the particles of the yellow sol, are negatively charged (as shown by an electrophoretic experiment) like the copper particles, thus rendering coagulation unlikely.

These experiments led to many observations on the formation of copper mirrors on the walls of the glass vessels, the reduction of an ammoniacal copper solution by hydrazine hydrate being a particularly suitable method of preparing them. As Kohlschütter and Fischmann (*loc. cit.*) observed with silver mirrors, the substance which is specially important is the metal oxide: this must be present in sufficiently large amount; hence only a small excess of ammonia is favourable, the degree of dissociation of the copper–ammonia complex then being high. The copper oxide is markedly adsorbed on the glass, the two substances having opposite charges, and it must be reduced there more rapidly than in the liquid. Since a rapid reduction is also favoured by a higher temperature, the glass wall of the vessel must be sufficiently hot. If a test-tube filled with cold water is dipped into the solution in which the copper compound is being reduced, no mirror is formed on its wall. With the same total amount of ammonia, the copper–ammonia complex may be considered to be more dissociated than the silver complex (Gaus, *Z. anorg. Chem.*, 1900, **25**, 236; Dawson and McCrae, *ibid.*, 1901, **26**, 94); hence a large excess of ammonia, causing a decrease in the amount of colloidal metal oxide, need not be avoided so carefully with copper as with silver.

Under the conditions favouring the production of good copper mirrors, copper sols are formed in the liquid which appear to be coagulated by copper oxide (or hydroxide). They are dark brown in reflected and greyish-green in transmitted light; if the reduction is allowed to continue, the colour changes to copper-red in reflected and bluish-green in transmitted light, *i. e.*, the adsorbed oxide is reduced, a coarse copper sol being formed. The amount of oxide advantageous for the mirror is obviously too large for the sol, for it may cause coagulation. For preparing more highly dispersed sols, a larger but not too high concentration of ammonia is favourable.

(3) Mercury sols of diverse particle size and colour could also be prepared by mixing various amounts of hydrogen peroxide solution with a nuclear mercury sol made by reducing mercuric chloride with hydrazine hydrate in an aqueous solution containing sodium hydroxide and sodium protalbinate.

SUMMARY.

1. Highly disperse silver sols, free from organic substances and suitable as nuclear sols, may be prepared by reducing an ammoniacal silver oxide solution with hydrazine hydrate, provided that small amounts of copper be present. The favourable influence of traces of copper for making silver mirrors is well known. Other metals, such as lead and zinc, similarly facilitate the formation of both sols and mirrors.

2. Substances, such as complex cyanides or excess of ammonia, known to have an unfavourable influence on the production of highly disperse gold sols, are equally disadvantageous with silver sols.

3. As with gold sols, phosphorus (in ether) favours the formation of a highly disperse silver sol so strongly that it is not necessary either to add an advantageous substance such as copper or to avoid impeding reagents such as excess of ammonia. Hydrogen phosphide acts like a solution of phosphorus.

4. Clear, amicronic, red sols of metallic copper, free from protecting colloids, are reproducibly prepared by reducing an ammoniacal solution of copper oxide with hydrazine hydrate and adding phosphorus (in ether), at higher temperatures. Phosphorus without

hydrazine hydrate does not produce such a sol, but instead, provided that the amount of phosphorus be sufficiently large, a brownish-black sol, probably containing copper phosphide particles. The production of the red copper sol is connected with the primary formation of a yellow sol whose particles, consisting presumably of copper phosphide, act as nuclei.

5. With ammoniacal copper oxide solution and hydrazine hydrate in absence of phosphorus, much coarser copper sols are produced. In these solutions copper mirrors are also readily formed. Mirrors are favoured by a smaller excess of ammonia than is advantageous for the formation of fairly disperse copper sols.

We are much indebted to the Educational Committee of Woburn House and to the International Student Service for personal grants to one of us (D. S.).

THE SIR WILLIAM RAMSAY LABORATORIES OF INORGANIC AND PHYSICAL CHEMISTRY,
UNIVERSITY COLLEGE, LONDON. [*Received, May 15th,* 1937.]

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226. *The Diffusion Coefficient of Methane and Air.*

By H. F. COWARD and E. H. M. GEORGESON.

As no measurement of the coefficient of inter-diffusion between methane and air appears to have been recorded, and as it is not possible to deduce a reliable figure from other data, the results of some experiments on this subject are now presented.

The method used was essentially that of Loschmidt (*Sitzungsber. Akad. Wiss.*, 1870, **61**, 367). A vertical tube, closed at the ends, was divided horizontally into two halves which could be put into communication or separated as desired. Two gases were allowed to diffuse for a definite period, and the contents of the two halves of the tube were then separated and analysed. On the assumption of Fick's (second) law of diffusion, $\partial c_1/\partial t = D\partial^2 c_1/\partial x^2$, the diffusion coefficient D was calculated from the equation

$$\frac{u - o}{u + o} = \frac{8}{\pi^2}\left(e^{-\pi^2 Dt/L^2} + \frac{1}{9}e^{-9\pi^2 Dt/L^2} + \frac{1}{25}e^{-25\pi^2 Dt/L^2} + \ldots\right) \quad . \quad . \quad (1)$$

in which u and o are the percentages of the heavier gas in the contents of the lower and the upper half of the tube, respectively, L is the length of the tube, and t the time of diffusion. McKay (*Proc. Physical Soc.*, 1930, **42**, 552) gives a table which facilitates the calculation of D.

EXPERIMENTAL.

Apparatus.—The diffusion tube was made, like that of Schmidt (*Ann. Physik*, 1904, **14**, 801), from two smoothly polished rifle-barrel tubes (*D*, *K*, Fig. 1). One end of each was threaded eccentrically into a wide circular flange, the other was closed by a flat cap. The flange of the lower tube was supported by the ring of a tripod that was fastened to the floor of the laboratory. The flange of the upper tube rested on that of the lower and could be rotated, by the aid of a handle *H*, in an orbit accurately defined by a guard ring, *J*. This sliding joint is simpler than the wide-bore stop-cock used by Schmidt as an improvement on Loschmidt's sliding shutter. Moreover, it avoids the use of conical surfaces which, if they become worn, may either allow the plug of the tap to enter too far and thus destroy the symmetry of the diffusion space, or, if this be prevented, offer the possibility of leakage. A tapered pin, *G*, drops through the upper flange and engages the lower when the tubes are accurately in line.

The sliding joint was lightly smeared with a rubber lubricant. We were unable to prevent the intrusion of a small amount of lubricant from the joint into the diffusion space. It was distributed as a thin film when the tube was filled by mercury, and when the tube was opened a few globules of mercury were found clinging to its wall. The maximum amount of mercury thus found was 0·06 c.c. and the amount of grease was very small. It seems improbable that an appreciable error could be introduced by these.

The cap *L* was drilled and fitted, flush with its inner surface, with one limb of a fine capillary glass tap, *N*, which led to a reservoir of mercury, *M*. The cap, *C*, was fitted in the same way with a 3-way fine capillary tap, *B*, leading to a supply of methane, to a manometer and "Hyvac" pump, to the atmosphere, and to a gas sampler, *A* (Fig. 2). A two-way capillary tap, *F*, was

fitted through the flange of the upper tube and could be brought in connexion with the lower tube by suitable rotation of the sliding joint. One of its branches led to a gas sampler, *E*, the other to a U-tube containing soda-lime and calcium chloride through which air could be drawn. The thick rubber tube connexions of the taps *B* and *F* allowed the tube *D* to be rotated.

The relevant dimensions of the apparatus were: Lengths of the lower and the upper tube, 529·4 and 528·5 mm. respectively. Volumes, 38·37 and 38·10 c.c. Mean internal diameters, 9·60 and 9·58 mm. Thickness of wall, 8·2 mm. The volume of the capillary glass tubing between steel tube and glass tap, 0·008 c.c. in both instances, was negligible.

The temperature of the diffusing gases was controlled by surrounding the diffusion tubes with Bell's asbestos "Viceroy" sectional pipe covering and by packing the ends and the middle flanges of the tubes with cotton-wool. The temperature recorded by thermometers embedded in the asbestos was found to remain constant within 0·3° during each experiment.

FIG. 1.

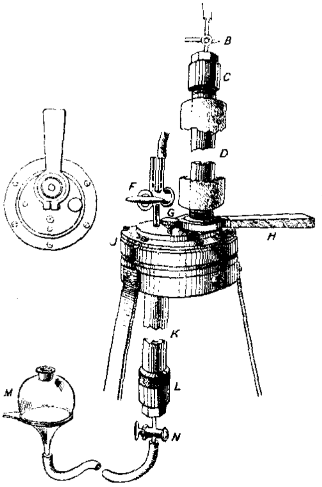
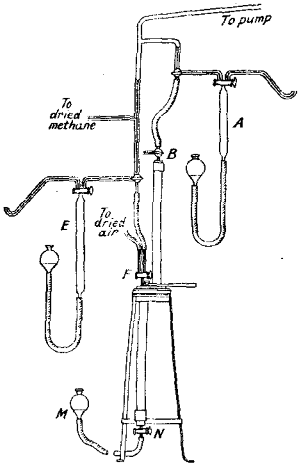


FIG. 2.



Gases.—The methane used was prepared from a good sample (94% pure) of fire-damp, twice liquefied and distilled, the first and last thirds of the distillate being rejected each time. The product was indistinguishable from pure methane by analysis in a Bone and Wheeler apparatus. The air used was drawn slowly over soda-lime and calcium chloride.

Method of Experiment.—At the beginning of each experiment the two halves of the diffusion tube were put in connexion and the air in them was displaced, through *B*, by mercury from *M*. Meanwhile the system between the methane holder and the diffusion tube was evacuated and then filled to the taps *B* and *F* with methane. By suitable manipulation of *M* and *B*, *D* was flushed with methane and finally filled with that gas at slightly more than atmospheric pressure. The two halves of the diffusion tube were then disconnected. The lower half was well flushed and finally filled with air, the mercury being left at a point just above the barrel of the tap *N*, which was then closed. The gases in *D* and *K* were brought to atmospheric pressure by momentarily opening the taps *B* and *F* to the air.

The interdiffusion of the gases was started by turning the upper tube until the pin *G* fell and locked the tubes in line. During each experiment the temperatures of thermometers embedded in the asbestos were read at intervals, and the barometer reading was taken. Just before the

end of the diffusion period the branches of the apparatus were evacuated, tap F being turned so that the capillary space between it and the sliding joint was also evacuated. Tap F was then shut and, at a definite moment, the diffusion was stopped by turning the upper tube out of line with the lower. The apparatus was allowed to stand overnight to permit the contents of the two halves of the tube to become homogeneous. Samples were then withdrawn by means of A and E, and analysed.

According to Fick's law, which is true or nearly so for all gases with which it has been tested, the diffusion coefficient is independent of time. Hence for these experiments a period of diffusion was chosen (about one hour) in which the errors of experiment would least affect the results.

The apparatus was tested at intervals for leakage, but none was detected, either between the halves of the diffusion tube when fully turned out of line or between the tube and the atmosphere.

Results.

As a preliminary check, the diffusion coefficient of carbon dioxide and air was determined. The value found was $0{\cdot}139 \pm 0{\cdot}003$ cm.²/sec., corrected to 0° and 760 mm. pressure, in comparison with previous determinations ranging from 0·130 to 0·142 cm.²/sec.

The measurements for the diffusion of methane and air are given in the table; u and o have virtually the same significance as on p. 1085, but actually they refer to the methane found in the upper and in the lower half of the tube at the end of the experiment. The values of $u + o$ serve to check the tightness of the apparatus against diffusion from the outer air; they show that rarely, if ever, was error introduced by leakage to the outer air while the contents of the separated halves of the tube stood overnight before they were removed; for the analytical error in $u + o$ may approach 0·4. As the lower half of the tube was about 0·7% larger than the upper, the actual value of $u + o$ in these experiments would be $100 - 0{\cdot}7 \times 0{\cdot}30 = 99{\cdot}8$.

Duration of expt., mins.	u.	o.	$u + o$.	Temp.	Press., mm. Hg.	D.	$D_{0°,760}$. $m = 2$.	$m = 1{\cdot}75$.
60	70·6	29·8	100·4	16·8°	750	0·218	0·191	0·194
60	70·0	30·0	100·0	18·7	749	0·222	0·192	0·195
60	70·5	29·5	100·0	18·3	754	0·215	0·187	0·190
60	70·3	29·9	100·2	16·9	753	0·220	0·193	0·196
60	69·8	30·1	99·9	15·8	756	0·225	0·200	0·203
60	70·1	29·5	99·6	15·8	759	0·216	0·193	0·195
60	69·9	30·0	99·9	17·6	763	0·223	0·198	0·201
60	69·7	29·9	99·6	18·1	761	0·222	0·196	0·199
63	69·4	30·6	100·0	17·0	760	0·221	0·196	0·199
61	69·5	30·3	99·8	17·2	760	0·225	0·199	0·202
60	70·0	30·0	100·0	18·6	751	0·222	0·192	0·196
60	69·7	30·2	99·9	17·5	749	0·226	0·197	0·200
60	69·5	30·3	99·8	19·5	755	0·228	0·197	0·201
60	70·0	30·2	100·2	21·3	763	0·225	0·195	0·198
60	69·5	30·5	100·0	21·6	763	0·230	0·198	0·202
60	69·7	30·2	99·9	20·6	763	0·226	0·196	0·200
60	70·1	30·0	100·1	19·2	765	0·222	0·195	0·198

The values of D may be reduced to a common temperature and pressure by means of the equation $D_{0°,760} = D_{t,p}(p/760)(273/T)^m$. The value of m is unknown, but for other pairs of gases it lies between 2·00 and 1·75. The values of $D_{0°,760}$ are tabulated for each of these values of m. Their means, which are 0·195 and 0·198 respectively, do not differ enough, in view of the experimental errors, to warrant a determination of m for the sake of the reduction of D to 0°. The true value of $D_{0°,760}$ is probably close to 0·196 cm.²/sec.

We thank the Safety in Mines Research Board for permission to publish this communication, and acknowledge the help of the Electrical Section of these laboratories in designing and making the diffusion tube.

Safety in Mines Research Board Laboratories, Sheffield. [*Received, April 28th,* 1937.]

227. *The Moments of Coumarin and its 3-Phenyl Derivative and of Certain Substituted γ-Pyrones.*

By C. G. Le Fèvre and R. J. W. Le Fèvre.

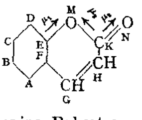
The dipole moments of a number of substances related to α- and γ-pyrones are now recorded. The only previous measurements in this class were made by Hunter and Partington (*J.*, 1933, 87), who reported a slightly lower moment for dimethylpyrone than that now found by us. Recently, however, Govinda Rau (*Proc. Indian Acad. Sci.*, **1936**, *A*, **4**, 687) has published data for both this compound and coumarin, which we also had under investigation. His observations and ours are in substantial agreement in both cases.

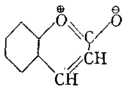
A table of the present and past results is given below beneath the customary headings:

	Substance.	$_EP + {_AP}$, c.c.	$_TP$, c.c.	Temp.	μ.*	Authors.
I.	Coumarin	42	457	25°	$4{\cdot}4_6$	Le F. & Le F.
		48·5	477·6	20	$4{\cdot}5_1$	G. R.
II.	3-Phenylcoumarin	69	451	25	$4{\cdot}3_0$	Le F. & Le F.
III.	2 : 6-Dimethyl-γ-pyrone	34	480	25	$4{\cdot}6_5$	,, ,,
		35	385	20	$4{\cdot}0_5$	H. & P.
		36	459·1	20	$4{\cdot}4_8$	G. R.
IV.	3 : 5-Diacetyl-2 : 6-dimethyl-γ-pyrone	53	394	25	$4{\cdot}0_6$	Le F. & Le F.
V.	2 : 6-Diphenyl-3 : 5-dimethyltetrahydro-γ-pyrone	84	151	25	$1{\cdot}8_0$	,, ,,
VI.	Dehydracetic acid	44	210	25	$2{\cdot}8_3$	,, ,,
VII.	2 : 6-Diphenyl-γ-pyrone	72	380	20	$3{\cdot}8_2$	H. & P.
VIII.	Xanthone	57	257	25	$3{\cdot}1_1$	Le F. & Le F.†
		60	240·9	20	$2{\cdot}9_3$	G. R.

* Moments, here and throughout, are expressed in Debye units.
† This vol., p. 196.

Coumarin and 3-Phenylcoumarin.—The two chief moments in these molecules are those of the C–O–C and the C=O units. These (1 and 2·3 respectively) interact at *ca.* 60° and should, therefore, produce a resultant of about 2·9 roughly 17° anticlockwise to the axis of the carbonyl group in (I). Actually, however, the observed moments are considerably higher. This difference can very largely be attributed to intramolecular electrostatic induction, an estimation of which for the two compounds has been made by the method described by us (this vol., p. 196). For (I) we have adopted a model (see I) with the following specification: Bonds AB, BC, CD, DE, EF, KM, ME, and FA, 1·42 A.; FG,

(I.) 

 (Ia.)

1·49 A. (cf. phthalocyanine, Robertson and Woodward, this vol., p. 219; diphenyl, Clark and Pickett, *J. Amer. Chem. Soc.*, 1931, **53**, 167, 3820); GH and KN, 1·32 A. (cf. benzoquinone, *Proc. Roy. Soc.*, **1934**, **146**, 106, 473; *Nature*, 1934, **134**, 138); HK, 1·5 A. The points of action of the principal dipoles were taken to be the mid-points between the centres of the carbon and oxygen atoms in each case, the values being 1·01, 1·01, and 2·3 units for μ_1, μ_2, and μ_3 respectively, directed along the interatomic links as indicated on the diagram. The polarisabilities at the various atomic centres are stated in our previous paper. In the present case, however, EM and KN being only 1½° from parallel, the calculations were simplified by ignoring this slight divergence and regarding the directions of μ_1 and μ_3 as identical.

The equations used are those of Smallwood and Herzfeld (*J. Amer. Chem. Soc.*, **1930**, **52**, 1919) giving the horizontal and the vertical component (μ_x and μ_y) of the induced doublet produced in a particle of polarisability α situated r length units away from the primary

dipole whose direction makes an angle θ with r. The $\Sigma\mu_{x+y}$ values so calculated were reduced by the factor $(\epsilon + 2)/3\epsilon$ as suggested by Frank (*Proc. Roy. Soc.*, 1935, *A*, **152**, 188), ϵ being taken as 2·4 (Le Fèvre and Le Fèvre, *loc. cit.*). The results are tabulated:

Coumarin.

From $\mu_1\begin{cases}\Sigma\mu_x = +0{\cdot}50\\ \Sigma\mu_y = -0{\cdot}42\end{cases}$ From $\mu_2\begin{cases}\Sigma\mu_x = +0{\cdot}27\\ \Sigma\mu_y = +0{\cdot}75\end{cases}$ From $\mu_3\begin{cases}\Sigma\mu_x = +0{\cdot}95\\ \Sigma\mu_y = +0{\cdot}43\end{cases}$

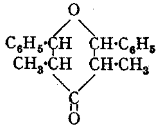
(A negative sign shows that the induced acts against the primary dipole.)

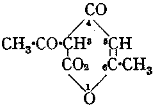
Resolution by graphical methods of the three primary and six induced component moments gave a resultant of 4·05 units acting along a direction inclined anticlockwise 15° to the axis of the C=O group and with its negative end pointing away from the molecule.

Similar treatment for 3-phenylcoumarin [on the basis of a model derived from (I) with the C–C link from H to the carbon of the substituent group 1·49 A., and with the remaining carbons separated by the normal aromatic internuclear distances] shows that at the centre of the 3-phenyl ring the total induced moments from μ_1, μ_2, and μ_3 amount to *ca.* —0·2 to —0·3 and act parallel to the C=O axis (α has been taken as $0{\cdot}9 \times 10^{-23}$ c.c., *i.e.*, the mean α for the breadth and thickness of benzene as given by Stuart and Volkmann, *Ann. Physik*, 1933, **18**, 121). This is in good agreement with experiment, by which the moment of phenylcoumarin is found to be *less* than that of its parent by approximately this amount.

In both cases the observed moment exceeds that calculated by about 0·5 unit. Following Sutton (*Trans. Faraday Soc.*, 1934, **30**, 793), this increase can be attributed to resonance between the normal molecule (I) and excited states [the chief being probably (I*a*), which corresponds to a formula proposed by Clayton (J., 1908, **93**, 524)], or, using other descriptions of the same phenomenon, to *mesomerism* (Ingold, J., 1933, 1120), or the existence of "Zwischenstufen" (Arndt and co-workers, *Ber.*, 1930, **63**, 587, 2963). (It should be noted, however, that the *idea* of permanent valency displacements occurring by the mechanism of the tautomeric effect was clearly expressed by Ingold, *Ann. Reports*, 1926, **23**, 134, 149.)

The γ-Pyrone Derivatives.—The induction occurring in the two 2 : 6-disubstituted-γ-pyrones has also been estimated, by using the appropriate dimensions listed above, but the resultant moments so calculated are several units below those found by direct measurement. It is clear, therefore, that, even more definitely than xanthone, these molecules in their real states are mesomerides between the ketonic and betaine forms: O=C<(C=C)(C=C)>O and $^{\ominus}$[O—C<(C—C)(C=C)>O]$^{\oplus}$. Compound (V) is notable in this connection in that, owing to the absence of conjugation between the ethereal oxygen and the carbonyl group, mesomeric effects are absent and the observed moment is of the low order to be expected if the real state were practically as formulated.

(V.) 

 (VI.)

The moment found for dehydracetic acid is in agreement with structure (VI) (cf. Adams and Rassweiler, *J. Amer. Chem. Soc.*, 1924, **46**, 2758) if the 3-acetyl group is restricted in its rotation (about the bond joining it to carbon atom no. 3) to the plane dividing the molecule perpendicularly through the carbon atoms 3 and 6.

Measurements.—These were made at 25° and approximately 1200 kc. The columns contain the following data respectively: (1) the weight fraction of the solutes in the solutions, (2) the dielectric constants of the solutions, (3) their densities, (4) their specific polarisations, (6) their refractive indexes, (7) their specific refractions, and (5) and (8) the

molecular polarisations and refractions of the solutes. The formula of Sugden (*Trans. Faraday Soc.*, 1933, **30**, 720) has been used in the calculations.

$w_1 \times 10^6$.	$\epsilon_{25°}^{1200}$.	$d_{4°}^{25°}$.	P_{12}.	P_1.	$n_D^{25°}$.	r_{12}.	$[R_L]_D$.
0	2·2725	0·87378	0·34086	—	1·49724	0·33503	
			Coumarin; M = 146·1.				
11,670	2·4546	0·87698	0·37236	444·2	1·49835	0·33436	41·6
16,260	2·5305	0·87830	0·38464	443·2	1·49885	0·33422	41·7
25,039	2·6747	0·88070	0·40677	434·4	1·49979	0·33384	42·0
			3-Phenylcoumarin; M = 222·2.				
6,044·8	2·3291	0·87552	0·35067	436·3	1·49808	0·33484	(67·5)
8,815·2	2·3538	0·87629	0·35485	428·4	1·49857	0·33483	69·4
11,463·5	2·3765	0·87690	0·35868	421·1	1·49887	0·33476	69·2
			2 : 6-Dimethyl-γ-pyrone; M = 124·1.				
2,838·1	2·3270	0·87436	0·35075	474·8	1·49731	0·33485	33·7
3,763·5	2·3437	0·87451	0·35373	466·7	1·49731	0·33479	33·7
5,933·8	2·3853	0·87495	0·36104	464·4	1·49739	0·33467	34·0
8,213·3	2·4263	0·87546	0·36807	453·4	1·49751	0·33454	34·2
			3 : 5-Diacetyl-2 : 6-dimethyl-γ-pyrone; M = 208·2.				
2,102·1	2·2910	0·87430	0·34412	393·8	—	—	—
2,712·0	2·2962	0·87446	0·34502	390·3	1·49726	0·33478	(50·6)
5,969·9	2·3248	0·87522	0·35000	389·7	1·49737	0·33455	53·0
6,054·9	2·3254	0·87525	0·35010	388·7	1·49739	0·33455	53·2
			2 : 6-Diphenyl-3 : 5-dimethyltetrahydro-γ-pyrone; M = 280·3.				
6,403·1	2·2818	0·87503	0·34211	150·3	1·49773	0·33483	85·1
9,927·6	2·2870	0·87572	0·34282	150·3	1·49791	0·33467	83·7
18,832	2·2992	0·87742	0·34441	149·7	1·49842	0·33431	83·2
			Dehydracetic acid; M = 168·1.				
1,110·4	2·2785	0·87410	0·34186	208·7	1·49731	0·33495	44·2
1,601·1	2·2811	0·87424	0·34229	207·4	—	—	—
2,620·8	2·2865	0·87452	0·34319	206·7	1·49742	0·33485	44·8
4,484·7	2·2962	0·87504	0·34479	204·6	1·49744	0·33466	42·5

UNIVERSITY COLLEGE (UNIVERSITY OF LONDON). [*Received, May 13th*, 1937.]

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228. *The Radioactivity of Potassium prepared from Animal Tissue.*

By A. LASNITZKI and E. A. OESER.

As a result of theoretical considerations, Klemperer (*Proc. Roy. Soc.*, 1935, *A*, **148**, 638) and Newman and Walke (*Phil. Mag.*, 1935, **19**, 767) suggested that the "natural" radioactivity of potassium is due to a very small amount of an isotope of mass number 40: this isotope was subsequently discovered by Nier (*Physical Rev.*, 1935, **48**, 283; 1936, **50**, 1041) and by Brewer (*ibid.*, 1935, **48**, 640). Its connection with the radioactivity was recently confirmed by Smith and Hemmendinger (*ibid.*, 1937, **51**, 178). Although it is true that this isotope is present in all known potassium salts to the same extent, yet it appeared questionable whether this would be the case for the potassium contained in living tissues. Ernst (*Naturwiss.*, 1934, **22**, 479) reported that potassium of animal origin shows a greater activity, as detected by the photographic method, than potassium of mineral origin. A similar result was obtained by Loring and Druce (*Chem. News*, 1930, **140**, 34) with potassium prepared from potato plants. In view of the importance of the question, we carried out the present investigation.

The whole muscular tissue of three adult rabbits, taken immediately after the animals had been killed, was finely minced and twice extracted in boiling distilled water. The extracts, from each animal separately, were concentrated to a small volume, rendered as far as possible free from protein, and the potassium* precipitated as perchlorate, which, after being separated,

* Estimations of potassium in the muscle residue indicated that nearly all of it present in the fresh tissue was extracted.

was washed with absolute alcohol. The dry potassium perchlorate was then converted into chloride by ignition. This, after being recrystallised several times, was dissolved in a small amount of water. In one case the solution contained 2·75 g. of the chloride in 10 c.c. of water, and in the other two cases a saturated solution was used.

The activity of these solutions was measured by means of a Geiger–Müller counter and compared with that of control solutions of the same concentration which had been prepared from ordinary potassium chloride (A.R.). For this purpose the solutions were pipetted into a glass mantle with a very thin interior wall, which fitted over the counter.

It was found, in all cases, that the activity of the "tissue potassium" was, within the statistical error, identical with that of the potassium of mineral origin. In some of our measurements the error was reduced to about 2%, so we conclude that the content of $^{40}_{19}K$ in the two kinds of potassium cannot differ by more than is indicated by this limit.

THE UNIVERSITY, MANCHESTER. [*Received, April 23rd*, 1937.]

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229. *Kationoid Reactivity of Aromatic Compounds. Part III. The Action of Piperidine on* meso*Benzanthrone.*

By WILLIAM BRADLEY.

In Part I (J., 1932, 1254) Bradley and Robinson described the direct replacement of the nuclear hydrogen of several aromatic nitro-compounds by piperidine, and the present part deals with substitution by the same reagent in an aromatic carbonyl compound. From the standpoint of the present work the most reactive ketone is *meso*benzanthrone, which reacts slowly with piperidine even in the absence of condensing agents. The reaction rate is greatly accelerated by sodamide, and when oxygen is present the main product, 2-piperidino*meso*benzanthrone, may be obtained in almost theoretical yield. Experiments are described which indicate the stages in the substitution process. The first phase in the reaction is the formation of piperidide ions, and these react with free *meso*benzanthrone to form an anion which is easily oxidised by oxygen to 2-piperidino*meso*benzanthrone. The simple adduct, 2-piperidinodihydro*meso*benzanthrone, does not appear as an intermediate stage in the substitution process. There is no reaction at the carbonyl group. When oxygen is excluded, the reaction proceeds more slowly, and simple replacement of hydrogen by piperidine does not occur to any considerable extent. Instead, compounds are obtained which have the properties of hydroaromatic amines and are probably adducts of piperidine and *meso*benzanthrone.

*meso*BENZANTHRONE (I) shows two distinct types of reactivity conditioned by the character of the substituting agent. Nitration (Lüttringhaus and Neresheimer, *Annalen*, 1929, **473**, 259) and halogenation (Cahn, Owen, and Simonsen, J., 1933, **444**) occur in the *Bz*-nucleus. On the other hand the Grignard reagent affords 4-alkyl and -aryl derivatives (Allen and Overbaugh, *J. Amer. Chem. Soc.*, 1935, **57**, 740; Charrier and Ghigi, *Ber.*, 1936, **69**, 2211), and potassium hydroxide and potassium chlorate yield 2-hydroxy*meso*-benzanthrone (Perkin and Spencer, J., 1922, **121**, 479). Again, in the presence of potassium hydroxide, aniline and *meso*benzanthrone give 2-anilino*meso*benzanthrone in small amount (Lüttringhaus and Neresheimer, *loc. cit.*), and both acetone and phenylacetonitrile react to form 2-derivatives (B.PP. 319593, 322253, 338764).

In the latter group of reactions involving 2- and 4-substitution, the orientation of the entering substituent with respect to the carbonyl group recalls the additive reactions of the same reagents with αβ-unsaturated carbonyl compounds; but, whilst in general the aliphatic adducts are stable, the *meso*benzanthrone derivatives are formed from the reactants with loss of hydrogen.

The formation of piperidino*meso*benzanthrone by the action of piperidine and sodamide on *meso*benzanthrone has already been described (Part I, *loc. cit.*), and advantage has been taken of the ease with which this derivative can be isolated to study the course of the substitution reaction.

*meso*Benzanthrone and piperidine react slowly at the boiling point of the latter and in

the absence of condensing agents to form a basic derivative. The reaction is quicker in oxygen than in nitrogen, and is accelerated by potassium hydroxide and especially by sodamide.

The Reaction in Oxygen.—In toluene suspension, sodamide has little action on *meso*-benzanthrone at 95—105°, at which temperature rapid substitution occurs in presence of piperidine. On the other hand, piperidine reacts with sodamide at this temperature with liberation of ammonia and formation of a suspension, which, cooled, reacts vigorously with *meso*benzanthrone at 50—55° to give an orange-yellow base. The first phase in the substitution is thus the formation of piperidide ions and the reaction of these with free *meso*benzanthrone.

The basic constituents of the reaction product occur free, and can be completely extracted with dry benzene or light petroleum. No basic compound occurs in the product as a sodium salt. When the reaction is carried out at 95—105°, the crude base is essentially 2-piperidino*meso*benzanthrone with very small amounts of stronger bases. The latter could not be purified completely, but their ability to reduce methylene-blue solution in the cold suggests that they are hydroaromatic amines.

Pre-formed sodium piperidide reacts easily with *meso*benzanthrone in oxygen even at the ordinary temperature, but in these circumstances the basic portion of the product consists largely of the stronger bases; in fact, these may form more than one half of the total amount of basic material.

The constitution of the 2-piperidino-derivative was established by its hydrolysis to 2-hydroxy*meso*benzanthrone, and by its formation from 2-acetoxy*meso*benzanthrone (Perkin and Spencer, *loc. cit.*) and piperidine.

2-Piperidino*meso*benzanthrone is relatively stable to hydrolysis. A suspension of sodium hydroxide in quinoline is almost without effect at 110°, but a slow reaction occurs with alcoholic potassium hydroxide at the same temperature. Fused potassium hydroxide readily hydrolyses the base at 250° with elimination of piperidine, but in these circumstances the main portion of the material is changed into a high-melting substance containing dibenzanthrone.

A characteristic feature of the substitution is the occurrence of phenols, mainly 2-hydroxy*meso*benzanthrone, in considerable amounts. The phenols result almost entirely by hydrolysis of the bases already formed, since it was shown in separate experiments that: (1) bases unaccompanied by phenols are formed when piperidine reacts with *meso*-benzanthrone in the absence of condensing agents; (2) phenols are formed with bases when the reaction is carried out in nitrogen and in presence of sodamide; (3) the proportion of bases increased rapidly to a maximum in the early stages of the reaction and subsequently decreased, whilst the proportion of phenols increased steadily throughout the reaction, as found by careful comparisons of the amounts of phenols and bases formed in a series of experiments of different duration; (4) only traces of phenols result by the direct oxidation of *meso*benzanthrone with oxygen in presence of sodamide at the temperature at which rapid substitution occurs; (5) the phenols are formed in much greater amount when sodium hydroxide is added to the reactants.

The slow rate of direct oxidation of *meso*benzanthrone, together with the small yield of 2-piperidino*meso*benzanthrone obtained by heating 2-hydroxy*meso*benzanthrone with piperidine, indicate that little or no 2-piperidino*meso*benzanthrone is formed by this route in the substitution reaction.

The Reaction in Nitrogen.—Under otherwise identical conditions the reaction between *meso*benzanthrone, piperidine, and sodamide proceeds much more slowly in nitrogen than in oxygen. Phenols are formed, and the bases occur free in the product and not as sodium salts. The carbonyl group of *meso*benzanthrone is clearly not involved in the reaction. The basic material is less homogeneous than that obtained in oxygen, and fractional extraction with hydrochloric acid from a solution in benzene shows it to consist of 2-piperidino*meso*benzanthrone and a stronger base. The former is usually present in very small amount. The stronger base is probably a hydroaromatic amine, since it reduces methylene-blue in the cold, and on heating, it hydrogenates azobenzene to hydrazobenzene and aniline. It has not yet been obtained pure. When it is freshly isolated and dried in a vacuum at

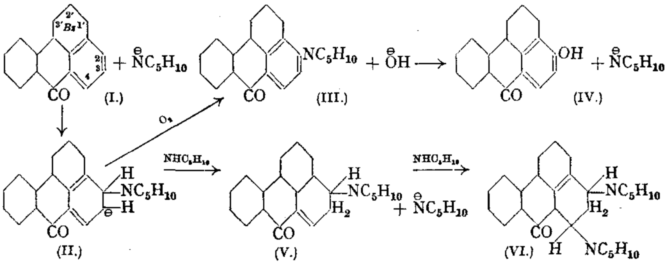
the ordinary temperature, the nitrogen content (5·5%) is considerably higher than that of 2-piperidino*meso*benzanthrone (4·5%). Possibly it consists of a mixture of the adducts formed from 1 mol. of *meso*benzanthrone and 1 and 2 mols. of piperidine severally. The formulation of the stronger base as a *meso*benzanthrone derivative is supported by the occurrence of 2-hydroxy*meso*benzanthrone in the phenolic portion of the product, and by the formation of a green fluorescent solution when the base is fused with potassium hydroxide at 250°. No carboxylic acid was formed in this hydrolysis, a circumstance which indicates that the base contains no acyl piperidide grouping. On heating, the base decomposes with evolution of piperidine and formation of a yellow sublimate which dissolves in concentrated sulphuric acid with a cherry-red coloration such as is given by most derivatives of *meso*benzanthrone.

Attempts to obtain piperidino*meso*benzanthrone by dehydrogenating the crude base with azobenzene, iodine, benzoquinone, dilute chromic acid, or methylene-blue were unsuccessful.

That the basic character must be ascribed to the occurrence of piperidino-groups appears certain, since sodamide, apart from salt formation, has no action on piperidine at the b. p. of the latter during 2 or 3 hours.

The following scheme is suggested as the probable course of the reactions taking place between piperidine and *meso*benzanthrone in presence of sodamide :

$$NaNH_2 + NHC_5H_{10} \longrightarrow NaNC_5H_{10} + NH_3$$



The first stage in the reaction is the formation of piperidide ions, and these react with free *meso*benzanthrone to form the anion (II). When the reaction occurs in oxygen at 95—105°, (II) is oxidised to 2-piperidino*meso*benzanthrone (III), and sodium hydroxide formed simultaneously hydrolyses a portion of the product to 2-hydroxy*meso*benzanthrone (IV) and piperidine. In nitrogen, oxidation of (II) is inhibited. Instead, the anion reacts with piperidine to form the adduct (V), which is a strong base with reducing properties. The analytical figures suggest that (V) reacts further with piperidine to form a derivative which is richer in nitrogen (VI ?). When pre-formed sodium piperidide reacts with *meso*benzanthrone in oxygen at the ordinary temperature, the substitution reaction (I ⟶ II ⟶ III) and the addition reaction (I ⟶ II ⟶ V) proceed at comparable rates, and the product is a mixture of the bases (III) and (V). There is no evidence that (III) can be formed from (V) by dehydrogenation during the reaction.

Experimental.

*Constitution of the Piperidino*meso*benzanthrone*, m. p. 178°.—(*a*) The base (2·5 g.), prepared according to Bradley and Robinson (*loc. cit.*), was added to potassium hydroxide (20 g.) and water (2 c.c.) at 200°, and the temperature raised to 250° during 15 minutes. Piperidine was eliminated. The product, when added to water, partly dissolved to a brown solution with a strong green fluorescence; on being filtered and acidified, this solution afforded 0·5 g. of a

phenol. Acetylated with acetic anhydride and sodium acetate, the phenol afforded 2-acetoxy-*meso*benzanthrone, m. p. 200—201° after recrystallisation from alcohol, alone or when mixed with an authentic specimen prepared according to Perkin and Spencer (*loc. cit.*). The alkali-insoluble portion of the product did not melt below 300°. It contained a considerable amount of dibenzanthrone, recognised by its violet colour, its bright red fluorescent solution in xylene, and its fluorescent reddish-violet solution in alkaline sodium hyposulphite (hydrosulphite).

(b) Piperidino*meso*benzanthrone (2·4 g.), stirred with a paste of potassium hydroxide (15 g.) and alcohol (30 c.c.) at 105—110° during 5 hours, gave 0·45 g. of 2-hydroxy*meso*benzanthrone, identified as the acetyl derivative.

(c) 2-Acetoxy*meso*benzanthrone (1·5 g.) was heated with piperidine (10 c.c.) at 200° during 8 hours. The precipitate obtained on pouring the product into water was collected, and extracted with hot concentrated hydrochloric acid. The deep orange solution, poured into water and basified with ammonia, afforded a canary-yellow precipitate which was collected, washed, dried, and recrystallised from light petroleum. The orange-yellow plates which separated melted at 178°, alone or when mixed with the base prepared by the action of sodamide and piperidine on *meso*benzanthrone (Found : N, 4·5. Calc. for $C_{22}H_{19}ON$: N, 4·5%).

The Action of Piperidine on meso*Benzanthrone in the Absence of a Condensing Agent.*—In the following experiments *meso*benzanthrone (9·2 g.) was boiled with piperidine (40 c.c.) under the conditions stated. In expts. 3 and 4 the apparatus used was wholly of Pyrex glass. The basic portion of the product was isolated by diluting the reaction mixture with water, collecting the precipitate, and extracting the bases with concentrated hydrochloric acid.

Expt. No.	Gas.	Time (hours).	Bases (g.).	Expt. No.	Gas.	Time (hours).	Bases (g.).
1	N_2	4	0·08	3	N_2	170	0·15
2	O_2	6	0·2	4	O_2	90	0·8

Experiments in Oxygen.—In the following experiments unless stated otherwise the quantities of reactants used were : *meso*benzanthrone (9·2 g.), sodamide (4·0 g.), and piperidine (40 c.c.).

(a) *The action of sodamide on* meso*benzanthrone.* The reactants were stirred in toluene (40 c.c.) at 100—105° during 2 hours; there was no apparent change. Dry benzene was added, and from the solution *meso*benzanthrone (8·9 g.) was recovered. The material insoluble in benzene was sodamide. Less than 0·1 g. of phenolic compounds could be isolated.

(b) *Direct oxidation of* meso*benzanthrone in presence of sodium hydroxide.* Phenols (0·03 g.) resulted when *meso*benzanthrone was stirred with finely powdered sodium hydroxide (4 g.) in dry quinoline at 105—110° during 1·5 hours. *meso*Benzanthrone (9·05 g.) was recovered. In piperidine solution, *meso*benzanthrone and sodium hydroxide (5 g.) gave 0·04 g. of phenols. *meso*Benzanthrone (8·5 g.) was recovered.

(c) *Comparison of the amounts of base and phenols formed in various reaction times.* Piperidine, *meso*benzanthrone, and sodamide were stirred together in a three-necked flask provided with a mercury seal. The enclosed air was displaced by oxygen, and the temperature slowly raised by heating in an oil-bath. When the inner temperature reached 75—80° there was a rapid evolution of ammonia which continued for 3—4 minutes, accompanied by darkening of the reaction mixture. The product was a mobile black liquid. After the times stated, at an inner temperature of 85—90°, dry benzene was added, and the extraction continued until nothing more dissolved. The residue was in each instance a light brown powder which was partly soluble in water to a brown solution with green fluorescence. Acidification of the filtered solution gave phenols in the amount stated below. The main constituent of this fraction was 2-hydroxy*meso*-benzanthrone. The material insoluble in benzene and water did not melt below 300°. Dibenzanthrone was absent, and no indication could be obtained of the presence of 2 : 2′-dibenzanthronyl. The benzene solution contained all the basic material and unchanged *meso*-benzanthrone. The bases were isolated by evaporating the solution, extracting the residue with hot concentrated hydrochloric acid, and precipitating the filtered solution with ammonia after adding ice. The basic fraction consisted almost entirely of 2-piperidino*meso*benzanthrone, but when the crude base was dissolved in benzene and the solution was extracted with hydrochloric acid of increasing concentration, a portion more strongly basic than the main constituent could be separated with 1% hydrochloric acid. Piperidino*meso*benzanthrone was not extracted in considerable amount with acid more dilute than 10% . The stronger base was present only in small amount, but it could be isolated from the crude base obtained in each experiment. It was an oily orange-yellow substance soluble in 0·5% hydrochloric acid to an orange solution which reduced methylene-blue in the cold. Addition of more concentrated acid to the dilute solution caused precipitation of a dark, oily hydrochloride.

Time (hours).	Soluble in benzene. Base (g.).	Soluble in benzene. Neutral (g.).	Insoluble in benzene. Phenols (g.).	Insoluble in benzene. Neutral (g.).	Time (hours).	Soluble in benzene. Base (g.).	Soluble in benzene. Neutral (g.).	Insoluble in benzene. Phenols (g.).	Insoluble in benzene. Neutral (g.).
0·25	0·5	8·5	0·22	0·2	2·0	10·05	0·1	0·52	0·6
0·5	7·2	2·5	0·30	0·3	4·5	7·95	0·1	1·16	1·95
1·0	6·0	2·5	0·22	0·2	5·0	7·0	0·8	1·37	2·0
1·75	9·35	0·1	0·43	0·45	6·0	7·95	0·1	1·52	?

(d) *Effect of added sodium hydroxide on the amount of phenols formed in the reaction.* When finely powdered sodium hydroxide (2 g.) was added to the reactants, and the products were isolated after 1 hour, the yields obtained were: base (3·2 g.), phenols (1·45 g.).

Experiments in Nitrogen.—(a) *Comparative experiments in oxygen and in nitrogen. Effect of amount of sodamide.* In the following experiments *meso*benzanthrone (4·6 g.) and piperidine (20 c.c.) were used.

Gas.	Time (hours).	$NaNH_2$ (g.).	Bases (g.).	Gas.	Time (hours).	$NaNH_2$ (g.).	Bases (g.).
O_2	1·5	1·0	2·6	O_2	3·0	1·0	2·6
,,	1·5	1·0	2·8	,,	5·0	1·0	2·6
N_2	1·5	1·0	0·95	,,	1·5	2·0	3·4
				N_2	1·5	2·0	1·7

(b) *Comparison of the amounts of bases and phenols formed in various reaction times.* In the experiments summarised below, the reactants were *meso*benzanthrone (9·2 g.), piperidine (40 c.c.), and sodamide (4 g.). The method of experiment was the same as that used in the oxygen experiments already described.

Expt. No.	Time (hours).	Bases (g.).	Phenols (g.).	Expt. No.	Time (hours).	Bases (g.).	Phenols (g.).
1	1·0	2·65	0·2	3	6·0	2·5	0·25
2	4·0	2·5	0·2				

(c) *Properties of the bases formed in nitrogen.* The crude base obtained in expt. 1 was washed with water after isolation, and dried over sulphuric acid in a vacuum [Found: N, 5·4, 5·5. Calc. for $C_{22}H_{21}ON$ (piperidinodihydro*meso*benzanthrone): N, 4·5%. Calc. for $C_{27}H_{32}ON_2$ (dipiperidinotetrahydro*meso*benzanthrone): N, 7·0%]. After several hours' drying at 100°, the nitrogen content was 4·5%.

A solution of the base in benzene was extracted with hydrochloric acid of increasing concentration. Almost the whole of the substance passed into 1% hydrochloric acid, forming an orange solution which reduced methylene-blue. The base remaining in the benzene solution was small in amount, and could only be readily extracted with concentrated hydrochloric acid. It appeared to be 2-piperidino*meso*benzanthrone. The stronger base was isolated, dried, and fused with azobenzene (10 g.) at 130—135° during 1 hour. The cooled melt, extracted with hot concentrated hydrochloric acid, afforded a solution from which benzidine hydrochloride crystallised on cooling. The salt was dissolved in hot water, and the solution filtered and mixed with dilute sulphuric acid. Benzidine sulphate was precipitated; yield, 0·6 g.

The crude base obtained in expt. 2 was treated as in the foregoing experiment, the more strongly basic fraction being fused with azobenzene (10 g.) at 130—135° during 1·5 hours. The cooled melt was dissolved in benzene and the solution extracted with 1% hydrochloric acid, and then with concentrated hydrochloric acid. The latter extract, diluted with water and basified with ammonia, gave a small amount of material, m. p. 80°, containing azobenzene. Attempts to separate a *meso*benzanthrone derivative by reducing the azobenzene to aniline were unsuccessful.

Low-temperature Experiments in Oxygen.—(a) *Sodamide and piperidine.* When piperidine (10 g.) was boiled with sodamide (3 g.) during 3 hours, and the suspension was cooled, mixed with water and excess of sodium nitrite, and then acidified with dilute acetic acid, nitrosopiperidine (9·0 g.), b. p. 190°/310 mm., was obtained. Piperidine (10 g.), which had not been heated with sodamide, gave on nitrosation 10·0 g. of nitrosopiperidine, b. p. 190°/310 mm.

(b) Piperidine (40 c.c.) was stirred with sodamide (4 g.) at 100° during ½ hour, then cooled, *meso*benzanthrone (9·2 g.) added, and stirring resumed at the ordinary temperature whilst a stream of oxygen was passed. After 24 hours the product was a viscous black mass. Almost all dissolved in cold benzene, and the solution, extracted with hydrochloric acid of increasing concentration, gave the following fractions: (1) soluble in 1% acid, 2·25 g.; (2) soluble in 5—10% acid, traces; (3) soluble in concentrated acid, 2·8 g. The stronger base was a brown solid with reducing properties. On heating, piperidine was evolved and a neutral yellow subli-

mate obtained which dissolved in concentrated sulphuric acid to an orange solution. When the base (1 g.) was fused with potassium hydroxide (20 g.) and water (2 c.c.) at 250° during 1 hour, piperidine was eliminated and a product obtained of which a small portion dissolved in water to a brown solution with greenish fluorescence. Only a trace of material was precipitated when the solution was acidified. The weaker base, an orange-yellow crystalline substance, m. p. 150—152°, gave pure 2-piperidino*meso*benzanthrone, m. p. 178°, when recrystallised from benzene.

The author is indebted to Imperial Chemical Industries Limited for grants and gifts of *meso*benzanthrone.

The College of Technology, University of Manchester. [*Received, May 26th,* 1937.]

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230. *Synthesis of* meso*Benzanthrones and Anthanthrones by the Ullmann Method.*

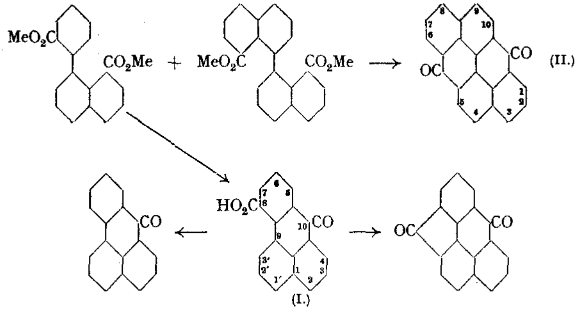
By H. Gordon Rule and F. Randall Smith.

The discovery that 8-bromo-1-naphthoic acid may be prepared readily from naphthalic acid (Rule and co-workers, J., 1934, 170) opens the way to the synthesis by Ullmann's reaction not only of substituted anthanthrones, but also of *meso*benzanthrones in cases where it is possible to obtain the unsymmetrical phenyl-naphthyl intermediates required for conversion into the latter group by cyclisation. Unfortunately the production of unsymmetrical dinuclear compounds by Ullmann's method cannot always be effected in good yield. Provided that the two halogen derivatives R_1X and R_2X are equally reactive towards copper bronze, an equimolecular mixture of them may be expected to give approximately equal proportions of the three products R_1R_1, R_2R_2, and R_1R_2. Apparently these conditions hold in the case of the *o*- and *m*-iodotoluenes, from a mixture of which the unsymmetrical 2 : 3-ditolyl has been isolated in a yield of 27—30% (Mayer and Freitag, *Ber.*, 1921, **54**, 356). But the halogen in one of the components may be rendered relatively inert through steric hindrance due to an adjacent group or alternatively become abnormally active owing to the presence of certain substituents in the molecule, with the result that the yield of the unsymmetrical dinuclear product is frequently diminished almost to vanishing point. In some cases, however, reactions of this type have been carried out successfully, as is illustrated by the coupling of iodobenzene and iodonaphthalene, respectively, with 2-chloro-3 : 5-dinitrobenzoic ester (Lesslie and Turner, J., 1930, 1758; 1931, 1188), from which the unsymmetrical derivatives were isolated in about 54% yields, no other products being detected.

The present communication deals with the reaction between 8-bromo-1-naphthoic ester and *o*-iodobenzoic ester, more particularly with the optimum conditions required for the formation of the unsymmetrical phenyl-naphthyl dicarboxylate and the influence exerted upon the course of the reaction by the introduction of substituents into the benzene and naphthalene nuclei. From the products so obtained, a number of derivatives of benzanthrone and anthanthrone have been isolated. Rule, Pursell, and Barnett carried out this reaction at 215—220°, using the iodobenzoic ester in 50% excess, and obtained pure crystalline methyl 8-*o*-carbomethoxyphenyl-1-naphthoate in a yield of 40% (J., 1935, 571).

In the experiments now described, the resulting reaction mixture of phenyl-naphthyl, dinaphthyl, and diphenyl derivatives was heated with sulphuric acid and the yields of the individual products were estimated from the amounts of 8-carboxy*meso*benzanthrone (I) and anthanthrone (II) obtained. Since the reaction with copper bronze was carried to completion, any iodobenzoate remaining unaccounted for was assumed to have been converted into diphenyldicarboxylic acid. All yields recorded below are calculated on the amount of bromonaphthoate employed, and on this basis the maximum yield of unsymmetrical derivative (75%) was obtained by use of two molecular proportions of iodobenzoate and a temperature of 180°; 11% of anthanthrone was also isolated, these two compounds corresponding to 86% of the original bromonaphthoate. Subsequently, experiments were carried out in which substituents were present in one or both of the reacting molecules, and, as the

material was insufficient for repeated preparations, the above conditions for the Ullmann reaction were adopted in each case. In general, 80—90% of the naphthoate could be



accounted for in this way. A summary of the more definite results is given in the table, two molecular proportions of the benzoic ester being used to one of the naphthoate except in No. 1, in which equal proportions were employed. The yields recorded could be repeated without difficulty.

Ullmann Reactions.

	Temp.	% Benzanthrone.	% Anthanthrone.
Methyl 8-*bromo*-1-*naphthoate in reaction with :*			
(1) Methyl *o*-iodobenzoate (1 mol. only)	195°	54	31
(2) Methyl *o*-iodobenzoate (2 mols.)	180	75	11
(3) Methyl *o*-bromobenzoate	180	41	44
(4) Methyl *o*-chlorobenzoate	180	—	71
(5) Methyl 5-bromo-2-iodobenzoate	180	60	28
(6) ,, ,, ,,	220	27	53
(7) Methyl 2-iodo-5-nitrobenzoate	180	41	43
(8) *Methyl 2-bromo-5-nitrobenzoate*	*180*	*33*	60
Methyl o-iodobenzoate in reaction with :			
(9) Methyl 5 : 8-dibromo-1-naphthoate	180	49	32
(10) Methyl 8-bromo-5-nitro-1-naphthoate	180	49	35
Methyl 5 : 8-*dibromo*-1-*naphthoate in reaction with :*			
(11) Methyl 5-bromo-2-iodobenzoate	180	49	38
(12) ,, ,, ,,	220	36	41
Methyl 8-*bromo*-5-*nitro*-1-*naphthoate in reaction with :*			
(13) Methyl 2-iodo-5-nitrobenzoate	180	—	75

As has already been stated, the experimental conditions adopted in No. 2 lead to a maximum yield of the unsymmetrical product, hence it is to be anticipated that smaller yields will result if the reactivity of either component is modified with respect to the other. Thus the activity of halogen in the iodobenzoate may be diminished by replacing iodine with bromine or chlorine (Nos. 3 and 4), or enhanced by introducing a nitro-group into the para-position to iodine (No. 7). Similarly, bromine in the bromonaphthoate may be further activated by the presence of a nitro-group * in position 5 (No. 10). In all of these cases the changes resulted in lower yields of the phenyl-naphthyl derivative.

Among other variations, reference may be made to No. 11, in which the modification of both reacting components by the introduction of bromine into the para-position to each halogen atom led to a reduction in the yield of phenyl-naphthyl derivative from 75% to 49%, and the corresponding introduction of *p*-nitro-groups (No. 13) resulted unexpectedly

* The activating influence of the 5-nitro-group has been proved in the reactivity of the bromine atom towards sodium methoxide (W. S. Haldane, Thesis, Edinburgh, 1934) ; but the effect of a 5-bromo-substituent (No. 9) in the above series is unexpectedly marked.

in the almost complete disappearance of the unsymmetrical product and a very high yield of anthanthrone.

In two instances (Nos. 6 and 12) the Ullmann reaction was carried out at 220° instead of 180°, in each case leading to an increase in the yield of anthanthrone at the expense of benzanthrone. Several other reactions in which difficulty was experienced in purifying the products or in effecting a conversion into benzanthrone are dealt with in the experimental section.

Three of the cases discussed above involve dihalogenated derivatives, but under the experimental conditions adopted there was no evidence of appreciable reactivity of halogen unless in the ortho- or peri-position to a carboxyl group. When 2 : 4-dibromobenzoic ester was employed as the benzenoid component, however, an inseparable mixture of derivatives produced by the coupling of both halogens was formed.

On the whole the effects of substitution support the view that the yield of unsymmetrical product is governed in part by the relative reactivities of the halogen atoms. Steric hindrance of the more active halogen is probably another controlling factor, visible in the interaction between picryl chloride and iodobenzene (Gull and Turner, J., 1929, **491**), which leads only to the isolation of 2 : 4 : 6-trinitrodiphenyl. According to Ullmann (*Annalen*, 1904, **332**, 38) iodobenzene does not react with copper bronze below 220°. This point has been confirmed during the present investigation, and it has been found, in addition, that no appreciable reaction occurs when the iodobenzene is in solution in boiling nitrobenzene at 205°. Picryl chloride, on the other hand, is so reactive that the mixture with copper bronze explodes at about 135°; although in boiling nitrobenzene the reaction proceeds smoothly to form hexanitrodiphenyl (Ullmann, *loc. cit.*). Gull and Turner used equimolecular quantities of reactants at 200—205° with gradual addition of copper bronze. No actual yield is recorded by these authors and it was considered of interest to repeat this work. At 195—203° the sole detectable product was trinitrodiphenyl, isolated in a yield of 75%. As it was not improbable that the temperature during this experiment might have risen locally to a point at which iodobenzene would normally be reactive, the change was carried out at 160—165°; the yield of 2 : 4 : 6-trinitrodiphenyl then increased to 85%. These results suggest that in the presence of picryl chloride the relatively non-reactive iodobenzene undergoes some special form of activation, permitting it to enter into reaction at a temperature much below that at which it would ordinarily do so.

meso*Benzanthrones*.—Ring closure of all of the phenyl-naphthyl dicarboxylic esters mentioned in the table to benzanthrone and hydrolysis of the remaining carboxylic ester group were complete after treatment with concentrated sulphuric acid for one hour at 100°. The substituted *meso*benzanthrone-8-carboxylic acids so prepared, *viz.*, the 1'-*bromo*-, 6-*bromo*-, 1' : 6-*dibromo*-, 1'-*nitro*-, and 6-*nitro*-derivatives, were yellow crystalline compounds which dissolved in sulphuric acid with a blood-red colour. The bromo-acids were soluble in alkali, forming orange to red solutions having a strong green fluorescence; the nitro-acids gave red non-fluorescent solutions.

When these acids were decarboxylated in boiling quinoline with addition of copper bronze, they gave rise to the corresponding substituted benzanthrones. 1'-Bromobenzanthrone melted at 176—177° and was identical with the product obtained by direct bromination of benzanthrone in acetic acid solution or in aqueous suspension. This synthesis therefore removes any remaining doubt that halogenation occurs primarily in the 1'-position. Further bromination is stated to yield a homogeneous product (Badische Anilin und Soda Fabrik, 1908, D.R.-P. 193,959), m. p. 256°, which must be designated as 1' : 6-*dibromo*-meso*benzanthrone*, since the compound obtained by brominating 1'-bromobenzanthrone in aqueous suspension is now found to be identical with that formed by decarboxylation of 1' : 6-dibromobenzanthrone-8-carboxylic acid. 6-Bromobenzanthrone, prepared by decarboxylation of the related acid, had a melting point of 183°, in agreement with that recorded for the product obtained by reducing 2 : 6-dibromobenzanthrone in alkaline medium (I.G., 1927; D.R.-P. 450,445).

The nitration of *meso*benzanthrone in nitrobenzene solution at 40—50° yields a mononitro-compound, m. p. 248—249°, in which the substituent occupies the 1'-position (B.P. 291,131, 1927); but in boiling acetic acid solution the main product is the isomeric 2'-nitro-

benzanthrone, m. p. 305—307° (Meister, Lucius, and Bruning, 1923, B.P. 224,522). In the present investigation 1'-nitrobenzanthrone prepared from the corresponding carboxylic acid melted at 248—249°, and was identified with the compound obtained by nitrating benzanthrone in nitrobenzene solution. Synthetic 6-*nitro*meso*benzanthrone* melted at 291—292°, and its melting point was strongly depressed by the second nitration product, m. p. 305—307°, obtained from benzanthrone in acetic acid solution.

Whereas the mononitro-derivatives obtained by direct nitration give orange non-fluorescent solutions in concentrated sulphuric acid, 6-nitrobenzanthrone forms a yellow solution with bright green fluorescence. 1' : 6-Dinitrobenzanthrone is also stated to give a similar fluorescence, which thus appears to be characteristic of the nitro-group in position 6. It was not found possible to effect the synthesis of the 1' : 6-dinitrobenzanthrone by the Ullmann method, or of the 5- or 7-nitro-compound.

In general, the oxidation of the substituted benzanthrones was not investigated, but 1'-bromobenzanthrone-8-carboxylic acid on treatment with chromic oxide was converted into the lactone of 1'-*bromo*-3'-*hydroxybenzanthrone*-8-*carboxylic acid* (cf. Grieve and Rule, this vol., p. 535).

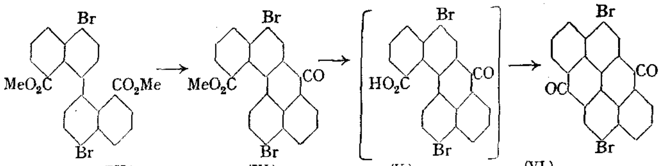
3' : 8-*Keto*meso*benzanthrones*.—Further ring closure between the 8-carboxyl group and the hydrogen atom in position 3' was brought about in a number of cases by heating the acid with phthalic anhydride and phosphoric oxide at 200° (cf. Bigelow and Rule, J., 1935, 573), thus leading to the related 3' : 8-keto*meso*benzanthrones in little short of quantitative yield. The 6-*bromo*-, 1'-*bromo*-, 1' : 6-*dibromo*-, 6-*nitro*-, and 1'-*nitro*-3' : 8-*keto*meso*benzanthrones* so obtained were crystalline compounds, ranging from orange to red, the 1'-nitro-derivative having the lightest colour and the dibromo-compound the deepest. In sulphuric acid they dissolve to give purple solutions. The melting points of these compounds and of the corresponding benzanthrones and their carboxylic acids show a curious irregularity. Whereas substitution by bromine or a nitro-group raises the melting point of benzanthrone or of its 8-carboxylic acid, that of the 3' : 8-keto-compound is lowered. This is particularly marked in the case of the 6-bromo-ketone, which melts 88° lower than unsubstituted ketobenzanthrone.

A characteristic property of the 1'-bromo-ketone is the sintering observed at a well-marked temperature varying between 180° and 200°, with no further change until the melting point at 326—328°. This sintering may be eliminated by previously raising the compound above its fusion point, but reappears if the compound is again recrystallised or thrown out of a sulphuric acid solution by addition of water.

Benzanthrones and ketobenzanthrones in general do not possess the properties of vat dyes, but no reference appears to be made in the literature to the fact that 1'-nitrobenzanthrone is readily reduced by alkaline hyposulphite (hydrosulphite) to a deep blue vat which deposits the pink amino-compound on aerial oxidation. *Methyl* 1' : 6-*dibromo*-7 : 8-*benzo*meso*benzanthrone*-4''-*carboxylate* (IV) also vats comparatively readily, giving a purple solution which deposits an orange ester on oxidation. Probably the reduction products in these cases are of the dihydrobenzanthrone type and not true leuco-compounds (cf. Bally and Scholl, *Ber.*, 1907, **40**, 1661).

Anthanthrones.—In the ring closure of 1 : 1'-dinaphthyl-8 : 8'-dicarboxylic ester with warm sulphuric acid it has been assumed by Kalb (*Ber.*, 1914, **47**, 1724) that the red intermediate stage corresponds to the existence of the half cyclised product, benzo*meso*benzanthronecarboxylic acid, which eventually undergoes further ring closure to form the green solution of anthanthrone. During the present work, however, it was found that, if the red solution obtained by heating methyl 4 : 4'-dibromo-1 : 1'-dinaphthyl-8 : 8'-dicarboxylate (III) with sulphuric acid for 10 minutes at 50° were poured into water, the ester (IV) was deposited in 50% yield, admixed with unchanged material. No free acid (V) or anthanthrone (VI) was detected. A similar result was obtained with the unbrominated ester, indicating that the monocarboxylic ester of type (IV) is relatively stable under experimental conditions which rapidly transform the free acid into anthanthrone. A comparison (carried out with the aid of Mr. J. S. Flanders) has shown that benzo*meso*benzanthronecarboxylic acid is converted by cold sulphuric acid into anthanthrone in two or three minutes, whereas the corresponding ester requires three days to effect the same change.

This stability is undoubtedly due to the increased steric hindrance offered to further hydrolysis after one carboxyl group has undergone ring closure, and thus brought the remaining



(III.) (IV.) (V.) (VI.)

ester complex into the same plane as the benzanthrone molecule, in spatial proximity to the 3′-position. In the related free acid, however, the carboxyl group is held rigidly in the position most favourable for rapid conversion of the compound into anthanthrone. It must therefore be concluded that the assumption made by Kalb (*loc. cit.*) is incorrect, and that the intermediate present in the red solution obtained by treating the dinaphthyldicarboxylic ester with sulphuric acid is predominantly benz*omeso*benzanthronecarboxylic ester and not the acid to which it gives rise on hydrolysis. The above dibromodinaphthyldicarboxylic ester passed into the anthanthrone much more slowly than the unsubstituted compound, requiring at least ten times as long at 50° to yield a pure green solution in sulphuric acid. This dibromo-anthanthrone has previously been prepared from 5-bromonaphthastyril by Corbellini and Barbaro (*Giorn. Chim. ind. appl.*, 1933, **15**, 335).

An isomeric 2 : 7-*dibromoanthanthrone* has also been synthesised (see p. 1102) by coupling two molecules of *methyl* 1 : 6-*dibromo-2-naphthoate* in presence of copper bronze, followed by treatment with chlorosulphonic acid. This dyes cotton a bright orange-brown colour in contrast to the pinker shade given by the 4 : 9-derivative.

Experimental.

The method of carrying out the Ullmann reactions and of working up the products is illustrated in the following case.

Methyl 8-bromo-1-naphthoate (4 g.) and methyl *o*-iodobenzoate (8 g., 2 mols.) were melted together with efficient stirring in a small stoppered flask immersed in an oil-bath at 180°. Copper bronze (4 g.) was added in small portions during 30 minutes, and stirring continued for a further 4 hours; the mixture was then cooled and extracted with 200 c.c. of acetone (in four portions), and copper and cuprous halide filtered off. Acetone was removed from the extract on the water-bath, and ether (40—50 c.c.) added; methyl 8-*o*-carbomethoxyphenyl-1-naphthoate then separated. It was filtered off and washed with a little ether. Weight, 2·75 g.; m. p. 131—132°.

This product was heated for 4 hours at 50° with concentrated sulphuric acid (40 c.c.), and the mixture cooled and poured into water. The yellow solid obtained was warmed with dilute alkali solution, leaving insoluble methyl *meso*benzanthrone-8-carboxylate (1·63 g.), m. p. 158—159°; acidification of the orange filtrate gave *meso*benzanthrone-8-carboxylic acid (0·8 g.), m. p. 270—272°.

The ethereal filtrate from the above mixed esters was freed from solvent, and the residue heated with 100 c.c. of concentrated sulphuric acid for 4 hours at 50°. After pouring into water an alkali-insoluble fraction (0·91 g.) was obtained containing anthanthrone and benzanthrone-8-carboxylic ester. The latter component was extracted with alcohol, giving 0·66 g., m. p. 157—159°, and leaving a residue of anthanthrone (0·25 g.) (total yield of benzanthrone derivatives, 75%; anthanthrone, 11%). The relative proportions of benzanthronecarboxylic acid and ester could be altered at will within wide limits by varying the length and temperature of the sulphuric acid treatment of the mixed esters.

Benzanthronecarboxylic acids were decarboxylated in boiling quinoline solution at 240° for 10—15 minutes in the presence of copper bronze. Cyclisation to 3′ : 8-keto*meso*benzanthrones was effected by phosphoric oxide in molten phthalic anhydride (Bigelow and Rule, *loc. cit.*).

With one exception the substituted naphthoic esters employed have already been described (J., 1934, 168, 171), and further reference need only be made to the following starting materials.

5 : 8-Dibromo-1-naphthoic acid has been obtained more readily and in greater yield by

boiling 8-bromo-1-naphthoic acid (30 g.) with glacial acetic acid (100 c.c.) and bromine (30 g.) under reflux for 4—5 hours. Almost pure dibromo-acid (34 g., 86% of the theoretical) is deposited on cooling, m. p. 230—232°.

Methyl 5-bromo-2-iodobenzoate, prepared in 77% yield from the corresponding acid, m. p. 158—159°, by means of methyl alcohol and sulphuric acid, crystallised from methyl alcohol in colourless needles, m. p. 45—46° (Found by sodium peroxide method: I, 37·0. $C_8H_6O_2BrI$ requires I, 37·2%).

6-Nitrophthalamic acid (Kahn, *Ber.*, 1902, 35, 3863) was converted by means of sodium hypochlorite solution into 6-nitroanthranilic acid, m. p. 189° (decomp.) (Found: N, 15·6. Calc. for $C_7H_6O_4N_2$: N, 15·3%) [Kahn, *loc. cit.*, records m. p. 180° (decomp.)], and thence into *2-iodo-6-nitrobenzoic acid*, Witt's method of diazotisation with potassium metabisulphite and fuming nitric acid giving a much purer product than could be obtained by use of sulphuric acid and sodium nitrite. Yield, 77%; m. p. 188—189° (from water) (Found: N, 5·05. $C_7H_4O_4NI$ requires N, 4·8%). *Methyl 2-iodo-6-nitrobenzoate* was best prepared by boiling the silver salt and methyl iodide under reflux for 3 hours. Yield, 80%; m. p. 94° (from methyl alcohol) (Found: N, 4·7. $C_8H_6O_4NI$ requires N, 4·6%). A considerable amount of tar was formed during an attempted esterification with thionyl chloride.

The succeeding paragraphs give a brief account of the *meso*benzanthrones and anthanthrones synthesised. The intermediate phenylnaphthyl- and dinaphthyl-carboxylates, where isolated, are described before the cyclised products to which they are related.

Methyl 5-bromo-8-(o-carbomethoxyphenyl)-1-naphthoate formed colourless needles from ligroin, m. p. 155° (Found: Br, 19·9. $C_{20}H_{15}O_4Br$ requires Br, 20·0%).

*Methyl 1'-bromo*meso*benzanthrone-8-carboxylate* crystallised in pale yellow needles from alcohol, m. p. 194° (Found: Br, 21·6. $C_{19}H_{11}O_3Br$ requires Br, 21·8%).

*1'-Bromo*meso*benzanthrone-8-carboxylic acid*, crystallised from alcohol and eventually from nitrobenzene, formed fine yellow needles, m. p. 315—316° (Found: Br, 22·3. $C_{18}H_9O_3Br$ requires Br, 22·6%).

1'-Bromo*meso*benzanthrone crystallised from chlorobenzene and finally from alcohol in yellow plates, m. p. 176—177°, unchanged on admixture with the direct bromination product of *meso*benzanthrone of the same m. p.

*1'-Bromo-3' : 8-keto*meso*benzanthrone* formed fine orange needles from acetic acid. Yield, 84%; m. p. 326—328°, sintering at 200°, resolidifying at 326°, and thereafter melting at 325—327° without sintering * (see p. 1099) (Found: C, 64·2; H, 2·0; Br, 24·3. $C_{18}H_7O_2Br$ requires C, 64·5; H, 2·1; Br, 23·9%). It is only sparingly soluble in hot alkaline hyposulphite, forming a yellow suspension in a greenish-brown liquid. Alkalis only attack the ketonic bridge on prolonged boiling (10% aqueous sodium hydroxide dissolves about 40% after 48 hours), giving an inseparable mixture, presumably of *meso*benzanthrone-3'- and -8-carboxylic acids.

The *lactone* of *1'-bromo-3'-hydroxy*meso*benzanthrone-8-carboxylic acid* was obtained by oxidising the bromo-acid with chromic oxide (compare Bigelow and Rule, *loc. cit.*). It crystallised from chlorobenzene in pale yellow needles, m. p. 321—323° (yield, 53%) (Found: C, 61·3; H, 2·0. $C_{18}H_7O_3Br$ requires C, 61·55; H, 2·0%). The compound is insoluble in cold alkali, but dissolves slowly on warming to give a purple solution with a red fluorescence. The original lactone is recovered on acidification.

Methyl 4 : 4'-dibromo-1 : 1'-dinaphthyl-8 : 8'-dicarboxylate was isolated from the Ullmann reaction with the mixed esters, and also in 55% yield from 5 : 8-dibromo-1-naphthoic ester and copper bronze at 210—220°. It formed colourless plates, m. p. 205°, from acetone (Corbellini and Barbaro, *loc. cit.*, found m. p. 204·5—205°, having prepared the ester from 5-bromonaphthastyril). When heated with sulphuric acid for 1 hour at 100°, the ester was quantitatively converted into 4 : 9-dibromoanthanthrone, which crystallised in deep red needles from nitrobenzene and functioned as an orange-red vat dye. When the sulphuric acid treatment of the ester (1·5 g.) was limited to 10 minutes at 50°, an orange precipitate was obtained on dilution with water. This was warmed with dilute alkali to remove any acidic compound; the filtrate, however, was not coloured and deposited no solid on acidification. The residue was extracted with hot acetone (30 c.c.) to remove unchanged starting material, leaving an orange residue of *methyl dibromobenzo*meso*benzanthronecarboxylate* (0·75 g.) in which only one of the two carboxyl groups originally present had undergone ring closure. This crystallised from acetic acid in square, deep orange

* The product obtained by direct bromination of keto*meso*benzanthrone behaves similarly (J. L. Grieve, in these laboratories).

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plates, m. p. 233° (Found : Br, 32·3. $C_{23}H_{12}O_3Br_2$ requires Br, 32·2%). The compound acts as an orange vat dye.

Methyl 7 : 8-*benzo*meso*benzanthrone*-4′-*carboxylate*, prepared in a similar way (3 minutes at 50°) by sulphuric acid treatment of the unbrominated 1 : 1′-dinaphthyl-8 : 8′-dicarboxylic ester in 50% yield, formed stout yellow needles, m. p. 154°, from alcohol (Found : C, 81·4; H, 4·2. $C_{23}H_{14}O_3$ requires C, 81·7; H, 4·2%).

6-*Bromo*meso*benzanthrone*-8-*carboxylic acid* formed yellow needles, m. p. 315—316°, from alcohol or nitrobenzene (Found : Br, 22·7. $C_{18}H_9O_3Br$ requires Br, 22·6%).

6-Bromo*meso*benzanthrone (55% yield) separated from alcohol or chlorobenzene in yellow plates, m. p. 182—183°.

6-*Bromo*-3′ : 8-*keto*meso*benzanthrone* (84% yield) formed orange needles, m. p. 239—240° (sintering at 230°), from acetic acid (Found : C, 64·4; H, 2·1. $C_{18}H_7O_2Br$ requires C, 64·5; H, 2·1%).

1′ : 6-*Dibromo*meso*benzanthrone*-8-*carboxylic acid* formed yellow needles, m. p. 354—356° (decomp.), from nitrobenzene (Found : Br, 36·7. $C_{18}H_8O_3Br_2$ requires Br, 37·0%).

1′ : 6-Dibromo*meso*benzanthrone (50% yield) was deposited from chlorobenzene in long yellow needles, m. p. 255—256°, unchanged on admixture with the dibromobenzanthrone, m. p. 255—256°, obtained by boiling the 1′-bromo-compound (1 g.) with bromine (0·6 g.) in aqueous suspension for 3 hours.

1′ : 6-*Dibromo*-3′ : 8-*keto*meso*benzanthrone* (90% yield) separated from chlorobenzene in fine red needles, m. p. 299—300° (Found : C, 52·2; H, 1·45. $C_{18}H_8O_2Br_2$ requires C, 52·2; H, 1·60%), soluble in sulphuric acid to a purple-red solution with blue fluorescence.

Methyl 5-*nitro*-8-o-*carbomethoxyphenyl*-1-*naphthoate* formed pale yellow needles, m. p. 154—155°, from ligroin (Found : N, 4·1. $C_{20}H_{15}O_6N$ requires N, 3·8%).

1′-*Nitro*meso*benzanthrone*-8-*carboxylic acid* crystallised in golden-yellow needles, m. p. 310° (decomp.) from acetic acid or nitrobenzene (Found : N, 3·8. $C_{18}H_9O_5N$ requires N, 4·4%).

1′-*Nitro*meso*benzanthrone* formed brown crystals, m. p. 248—249°, from toluene and did not depress the m. p. of the yellow 1′-nitro-derivative obtained by nitration of benzanthrone in nitrobenzene solution. The brown colour of the decarboxylation product appears to be due to the presence of a trace of colouring matter and is characteristic of the nitro-compounds prepared in this manner.

1′-*Nitro*-3′ : 8-*keto*meso*benzanthrone* (85% yield) separated in orange needles, m. p. 282—283° (sintering at 265°), from chlorobenzene (Found : N, 4·45. $C_{18}H_7O_4N$ requires N, 4·65%). It formed a purple-red solution in cold sulphuric acid.

6-*Nitro*meso*benzanthrone*-8-*carboxylic acid* formed yellow leaflets, m. p. 286—287° (decomp.), from nitrobenzene (Found : N, 3·9. $C_{18}H_9O_5N$ requires N, 4·4%).

6-*Nitro*meso*benzanthrone* crystallised in brownish needles, m. p. 291—292°, from acetic acid (Found : N, 4·8. $C_{18}H_9O_3N$ requires N, 5·1%). The m. p. was depressed to 255—285° by the direct (2′-) nitration product, m. p. 305—307°, obtainable from *meso*benzanthrone. The solution in sulphuric acid was yellow with bright green fluorescence.

6-*Nitro*-3′ : 8-*keto*meso*benzanthrone* formed deep orange needles, m. p. 316—317°, from chlorobenzene (Found : N, 4·25. $C_{18}H_7O_4N$ requires N, 4·65%). The yield obtained by the phthalic anhydride method was only 58% owing to the deposition of dark material which occluded some of the reactants. Dehydration in boiling nitrobenzene solution with phosphoric oxide (2 hours) gave a yield of 79%.

No homogeneous unsymmetrical products or their corresponding benzanthrone derivatives could be isolated from the Ullmann reaction between methyl 8-bromo-1-naphthoate and (*a*) methyl 2 : 4-dibromobenzoate, (*b*) methyl 2-iodo-4-nitrobenzoate, (*c*) methyl 2-iodo-6-nitrobenzoate, or between (*d*) methyl 8-bromo-5-nitro-1-naphthoate and methyl 2-iodo-5-nitrobenzoate, or (*e*) methyl 8-bromo-4 : 5-dinitro-1-naphthoate and methyl *o*-iodobenzoate.

Synthesis of 2 : 7-*Dibromoanthanthrone*.—1 : 6-Dibromo-2-naphthylamine was most satisfactorily prepared from benzylidene-β-naphthylamine in two stages (cf. Franzen and Eidis, *J. pr. Chem.*, 1913, **88**, 755). Yield, 74%; m. p. 122—123°. Trouble was encountered in applying the Sandmeyer reaction to the dibromo-amine, owing to the low solubility of the salts and the formation of an insoluble brown diazo-complex due to the diazotised base coupling with itself. The former difficulty was overcome by grinding the base to a fine suspension in hydrochloric acid, and the latter by reducing the acid concentration. 1 : 6-Dibromo-2-naphthylamine (60 g.) in a mixture of 60 c.c. of concentrated hydrochloric acid and 200 c.c. of water was reduced to a fine suspension by milling in a rotating bottle; the mixture was then diluted to 600 c.c. and stirred at 0° while sodium nitrite (15 g.) in 45 c.c. of water was added during 5 minutes with

addition of ice. Stirring was continued for 15 minutes and the yellow solution was then filtered from brown insoluble material (3 g.) and added slowly with stirring at 10° to a solution of cuprous cyanide (prepared from 90 g. of sodium cyanide in 400 c.c. of water, and 60 g. of copper sulphate crystals in 400 c.c. of water). Vigorous effervescence occurred and a light brown solid was deposited. After further stirring for 1 hour in the cold and another hour on the water-bath, the product was filtered off and washed. Yield, 59 g. The crude nitrile was boiled for 24 hours with a mixture of water (100 c.c.), sulphuric acid (200 c.c.), and glacial acetic acid (400 c.c.). On pouring into 3 l. of cold water a solid was obtained from which the dibromo-acid was extracted with hot dilute alkali, giving 33 g. of 1 : 6-dibromo-2-naphthoic acid, m. p. 235—240°. Crystallisation from nitrobenzene afforded 28 g. (42%) of pure acid, m. p. 249—250°.

Methyl 1 : 6-*dibromo-2-naphthoate*, prepared by use of thionyl chloride, crystallised from alcohol in colourless needles, m. p. 99—100°. Yield, almost quantitative (Found : Br, 46·8. $C_{12}H_8O_2Br_2$ requires Br, 46·5%).

The methyl ester (15 g.) was heated with copper bronze (10 g.) for 3 hours at 160—170°, the resulting paste extracted with acetone, and the extract concentrated until crystallisation set in. On filtration this gave 5·0 g. (41%) of *methyl* 6 : 6'-*dibromo*-1 : 1'-*dinaphthyl*-2 : 2'-*dicarboxylate*, which crystallised from acetone in rectangular plates, m. p. 220° (Found : Br, 30·6. $C_{24}H_{16}O_4Br_2$ requires Br, 30·3%). A somewhat lower yield was obtained by effecting dehalogenation in boiling xylene during a longer time.

Cyclisation of the dinaphthyldicarboxylic ester presented unexpected difficulty, treatment with sulphuric acid leading to extensive sulphonation. The ester was therefore hydrolysed with the above acetic acid and sulphuric acid mixture (4 hours), affording a high yield of practically pure 6 : 6'-*dibromo*-1 : 1'-*dinaphthyl*-2 : 2'-*dicarboxylic acid*, which separated from nitrobenzene in colourless plates, m. p. 342—344° (decomp.) (Found : Br, 31·6. $C_{22}H_{12}O_4Br_2$ requires Br, 32·0%). Although the corresponding acid chloride could not be cyclised by use of aluminium chloride in nitrobenzene at 100°, partial conversion into an impure anthanthrone was achieved by heating the acid with molten phthalic anhydride and phosphoric oxide at 200°. Chlorosulphonic acid, however, proved to be a most effective reagent for this purpose. The dicarboxylic acid (2 g.) was heated with redistilled chlorosulphonic acid (25 c.c.) for 30 minutes at 50°. On pouring into water, 2 : 7-*dibromoanthanthrone*, m. p. above 360°, was obtained in good yield. The orange-coloured solid gives a green solution in sulphuric acid and a deep violet vat with alkaline hyposulphite, which dyes cotton a deep orange colour. In boiling nitrobenzene it dissolves sparingly, depositing orange needles on cooling (Found : Br, 34·7. $C_{22}H_8O_2Br_2$ requires Br, 34·5%).

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EDINBURGH UNIVERSITY. [*Received, April* 21*st*, 1937.]

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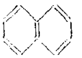
231. *The Structure of Naphthalene, Hydrindene, and Tetralin Derivatives.*

By (MISS) N. MCLEISH and NEIL CAMPBELL.

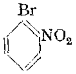
THE structure of naphthalene has been the subject of many critical investigations, and has recently been attacked from several different standpoints (Challenor and Ingold, J., 1923, **123**, 2066; Obermiller, *J. pr. Chem.*, 1930, **126**, 257; Bell, J., 1932, 2732; Fieser and Lothrop, *J. Amer. Chem. Soc.*, 1935, **57**, 1459; 1936, **58**, 2050; Sidgwick and Springall, J., 1936, 1532; Ufimzew, *Ber.*, 1936, **69**, 2188; Baker and Carruthers, this vol., p. 479). The problem cannot be regarded as solved, for, while Ufimzew (*loc. cit.*) concludes that a modification of the Erdmann formula (*Annalen*, 1893, **275**, 191)—an equilibrium between structures (I), (II), and (III)—affords the most satisfactory explanation of the properties of naphthalene derivatives (cf. Pauling and Wheland, *J. Chem. Physics*, 1933, **1**, 362), most of the evidence supports Fieser and Lothrop's conclusion (*loc. cit.*) that the Erlenmeyer formula (II) is the most acceptable to chemists. The chemical evidence rests chiefly on the reactivity of the 1-position and the non-reactivity of the 3-position in 2-substituted

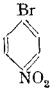
naphthalene compounds. This is explained by the presence of a double bond between C_1 and C_2, and a single bond between C_2 and C_3. Many of the reactions used in the past, however, do not provide convincing proof of the formula, as they are not necessarily dependent on the presence of double bonds. For instance, the isolation of 5 : 6-benzoquinoline as the sole product of the Skraup reaction with β-naphthylamine (Knueppel, *Ber.*, 1896, **29**, 708), though showing the marked reactivity of the 1-position, does not necessarily mean that this is caused by a double bond between C_1 and C_2. Such reactions are useful as indications,

(I.)  (II.) (III).

but must not be taken as conclusive evidence. It is therefore very desirable that the properties and reactions used in such investigations should be known to involve one or more double bonds. For this reason the investigations of Baker and Carruthers (*loc. cit.*) and Fieser and Lothrop (*loc. cit.*) provide the best evidence so far advanced for the arrangement of the double bonds in condensed aromatic compounds. The present paper gives further evidence on somewhat similar lines for the structure of derivatives of naphthalene, hydrindene, and tetralin.

Fuson (*Chem. Reviews*, 1935, **16**, 1) in his theory of vinylogy has pointed out that the influence of one functional group on another is observed not only in cases such as nitromethane but also when the groups are separated by carbon atoms linked by a double bond or a system of conjugated double bonds. For example, the mobility of the bromine atom in *o*- and *p*-bromonitrobenzene is due to the presence in the ring of a double bond and two conjugated double bonds, just as the reactivity of the methyl group in nitromethane is also found in *o*- and *p*-nitrotoluene.





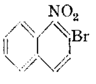
The reactivity of the bromine atom in aromatic bromonitro-compounds is therefore a method for detecting both the presence and the position of double bonds in aromatic compounds, and we have applied the method to bromonitro-derivatives of naphthalene, hydrindene, and tetralin. An analogous method was used by Mills and Smith (J., 1922, **121**, 2724) in the quinoline and *iso*quinoline series. Our work, like that of Fieser and Lothrop (*loc. cit.*) and Baker and Carruthers (*loc. cit.*), has the advantage that it overcomes the objections of Sutton and Pauling (*Trans. Faraday Soc.*, 1935, **31**, 939). It has also the advantage that semi-quantitative measurements can readily be made, and the reaction can be performed under mild conditions. The reactivity measurements were made by the piperidine method (cf. Le Fèvre and Turner, J., 1927, 1113), which proved to be the most suitable for the small quantities of compounds which were sometimes at our disposal. The measurements make no claim to accuracy, but are sufficient to show the relative reactivities of the bromine atom in the compounds examined. The results are in the table, and the details of the measurements in the experimental section.

	Percentage removal of bromine.	
	0·5 Hour.	20 Hours.
1-Bromo-2-nitronaphthalene	91	101
2-Bromo-1-nitronaphthalene	65	100
4-Bromo-1-nitronaphthalene	60	98
5-Bromo-1-nitronaphthalene	—	0
6-Bromo-2-nitronaphthalene	0	0
5 : 8-Dibromo-1-nitronaphthalene	0	0
3-Bromo-2-nitronaphthalene	0	0
1-Chloro-2-nitronaphthalene	51	—

	Percentage removal of bromine.	
	0·5 Hour.	20 Hours.
2-Chloro-1-nitronaphthalene	46	—
4-Chloro-1-nitronaphthalene	43	—
8-Chloro-1-nitronaphthalene	—	0
4-Bromo-5-nitrohydrindene	—	<5
6-Bromo-5-nitrohydrindene	—	72
6-Bromo-7-nitrotetralin	5	51
6-Bromo-5-nitrotetralin	0	0

If the Erlenmeyer formula is correct, the bromine atom in 1-bromo-2-nitronaphthalene,

2-bromo-1-nitronaphthalene, and 4-bromo-1-nitronaphthalene should be reactive, and in the other naphthalene compounds it should be non-reactive. The same applies to the corresponding chloronitro-compounds. If, on the other hand, the equilibrium formula of Erdmann (I ⇄ II ⇄ III) is correct, or an equilibrium between the structures (I) and (III) or (I) and (II) is accepted, 3-bromo-2-nitronaphthalene also must be reactive. In the naphthalene compounds studied (see table) a double bond exists between C_1 and C_2, and a single bond between C_2 and C_3. This rules out the equilibrium formulæ given above and confirms the Erlenmeyer formula. It is possible that the introduction of polar groups such as nitro- and bromo-groups into the naphthalene molecule, which is undoubtedly symmetrical (Kohlrausch, *Ber.*, 1935, **68**, 893), produces an unsymmetrical formula (Ufimzew, *loc. cit.*; Lesser, Kranepuhl, and Gad, *Ber.*, 1925, **58**, 2109) such as that inset, but the parallelism of our results with those of Fieser and other workers is strong evidence for the Erlenmeyer formula.

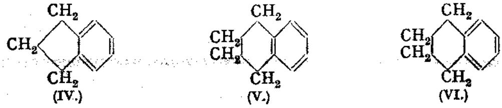


It might be expected that 6-bromo-2-nitronaphthalene would contain reactive bromine, as the bromine and the nitro-group are separated by a conjugated system of three double bonds. The fact that no reactivity was observed is another proof that the double bond shared by the two rings does not function normally. 8-Chloro-1-nitronaphthalene and 5 : 8-dibromo-1-nitronaphthalene also are of interest. In these compounds no reactivity was observed, although each contains a halogeno- and a nitro-group ortho to one another. It is clear that mere proximity of the groups is not sufficient to produce reactivity, and this fact confirms the correctness of Fuson's theory.

It must be stressed that all the chemical evidence for the structure of naphthalene rests on the properties and reactions of substituted naphthalene compounds. It is therefore possible that the polar effects of the substituents must be taken into account and what holds for one type of compound may not apply to others or to naphthalene itself. Thus the results of Baker and Carruthers (*loc. cit.*), as suggested by the authors themselves, may indicate in certain compounds an unsymmetrical distribution of bonds due to chelation between the substituents. Similarly there may be displacement of the double bonds by the use of vigorous conditions or reagents. This would account for the formation of 5 : 6-tetrahydrobenzindan-1-one from β-2-tetrahydronaphthylpropionyl chloride in presence of aluminium chloride (Darzens and Lévy, *Compt. rend.*, 1935, **201**, 902) and the formation of 2-hydroxy-3-naphthoic acid (Schmitt and Burkard, *Ber.*, 1887, **20**, 2702) by the action of carbon dioxide on sodium β-naphthoxide at a high temperature. The question of the mobility of the double bonds in naphthalene compounds can therefore only be settled by a thorough study of the reactions and properties of different types of naphthalene derivatives.

Attempts were made to prepare 8-bromo-1-nitronaphthalene in the same way as the chloro-compound, *i.e.*, action of the halogen on 1-nitronaphthalene, but 5-bromo-1-nitronaphthalene was invariably obtained. This may be due to an isomeric change caused by the hydrobromic acid liberated during the bromination converting the 8-bromo-1-nitronaphthalene first formed into the 5-bromo-compound in the same way that 1 : 8-dichloronaphthalene is converted into 1 : 5-dichloronaphthalene by the action of hydrochloric acid (Armstrong and Wynne, P., 1896—97, **13**, 154). For reactivity measurements 5 : 8-dibromo-1-nitronaphthalene and 8-chloro-1-nitronaphthalene were therefore used instead of 8-bromo-1-nitronaphthalene.

We also applied our methods to derivatives of hydrindene and tetralin. The work of Mills and Nixon (J., 1930, 2510) indicated that in hydrindene and tetralin the bonds were



(IV.) (V.) (VI.)

stabilised, and formulæ (IV) and (V) were advanced. Recent work by Fieser and Lothrop (*loc. cit.*), Sidgwick and Springall (*loc. cit.*), and Baker (this vol., p. 476) has confirmed

structure (IV) for hydrindene derivatives. Our results also are in agreement with this formula, as a double bond is shown to exist between C_5 and C_6 and a single bond between C_4 and C_5. The stabilised form for tetralin (V) may hold for the hydrocarbon as advocated by Mills and Nixon, but it apparently does not hold for all its derivatives. Thus, while the bromination and coupling reactions of 6-hydroxytetralin point to structure (V) (cf. Mills and Nixon, *loc. cit.*), the Skraup reaction on 6-aminotetralin (v. Braun and Gruber, *Ber.*, 1922, **55**, 1710) indicates a preponderance of form (VI). The fact that in all the reactions mixtures were obtained, and the work of Fieser and Lothrop (*loc. cit.*) and Sidgwick and Springall (*loc. cit.*) provides evidence that the bonds in tetralin derivatives are not fixed. Our observation that 6-bromo-5-nitrotetralin is completely non-reactive and 7-bromo-6-nitrotetralin reactive indicates structure (VI). It may be that the presence of the bromo- and the nitro-group does stabilise the molecule in this way, or it is possible that the reduced ring has some inhibiting effect on the bromine reactivity (cf. Lindemann and Pabst, *Annalen*, 1928, **462**, 24). It is impossible at present to decide between these alternatives.

Borsche and Bodenstein (*Ber.*, 1926, **59**, 1909) claimed to have obtained 6-bromo-5-acetamidohydrindene and 4-nitro-5-acetamidohydrindene by the bromination and nitration respectively of 5-acetamidohydrindene. From these two compounds we obtained the corresponding bromonitrohydrindenes by hydrolysis to the amino-compounds and replacement of the amino-group by the nitro-group in 6-bromo-5-aminohydrindene and by the bromo-group in the nitroaminohydrindene. The two bromonitrohydrindenes so obtained were found to be identical by a mixed melting-point determination and by measurements of the bromine reactivity. The nitro-compound obtained by Borsche and Bodenstein must therefore have been the 6-nitro- and not the 4-nitro-compound. It also follows that their product of the nitration of 5-acetylhydrindene must have been 6-nitro-5-acetylhydrindene and not 4-nitro-5-acetylhydrindene as they claimed. Doubt on some of the results of Borsche and Bodenstein had been cast by Lindner and Bruhin (*Ber.*, 1927, **60**, 439).

In one case, 4-bromo-5-nitrohydrindene, we were unable to purify the compound thoroughly, but quantitative analysis showed it to be sufficiently pure for a rough estimation of the bromine reactivity to be made.

EXPERIMENTAL.

Unless otherwise stated, the methods of preparation and the properties of the compounds used are those given in the literature. Many of the bromonitro-compounds were prepared from the corresponding nitroamines, the method of Hodgson and Walker (J., 1933, 1620) always being used. The identity and purity of the nitroamino-compounds were checked by the preparation of acetyl or benzoyl derivatives or of molecular compounds with *s*.-trinitrobenzene. The bromonitro-compounds in most instances were analysed quantitatively (Dr. Weiler, Oxford).

3-Bromo-2-nitronaphthalene.—1 : 3-Dibromo-β-naphthylamine was prepared as described by Bell (*loc. cit.*) and from it 3-bromo-β-naphthylamine was obtained as described by Consden and Kenyon (J., 1935, 1591). Attempts to oxidise the amino-group to the nitro-group by the methods of Meisenheimer and Hesse (*Ber.*, 1919, **52**, 1172) and Bigiavi and Albanese (*Centr.*, 1935, 1348) were unsuccessful. The compound was therefore converted into the nitro-compound by the method of Hantzsch and Blagden (*Ber.*, 1900, **33**, 2554). Copper sulphate crystals (10 g.) were dissolved in water (100 c.c.), and 2*N*-sodium hydroxide added until all the copper was precipitated as the hydroxide. The mixture was cooled in ice, and sulphur dioxide passed in until a dark green solution was obtained. When this was warmed, a red precipitate of cupro-cupri-sulphite (5 g.) was obtained. The amine (6 g.) was converted into the sulphate by the addition of sulphuric acid, water (25 c.c.) added to the paste, and the amine diazotised. A mixture of cupro-cupri-sulphite (10 g.), sodium nitrite (32 g.), and water (120 c.c.) was stirred mechanically, and the diazo-solution added drop by drop. The mixture was stirred at room temperature until the brisk evolution of gas had ceased, and then distilled with superheated steam. This method of separation was tedious owing to the low volatility of the 3-bromo-2-nitronaphthalene. The product (0·5 g.) crystallised from alcohol in pale yellow needles, m. p. 84° (Found: N, 5·7; Br, 33·4. Calc. for $C_{10}H_6O_2NBr$: N, 5·6; Br, 31·7%). Hodgson (J., 1936, 1151) gives the same m. p.

5-Bromo-1-nitronaphthalene.—This compound was prepared by a modification of Scheufelin's method (*Annalen*, 1885, **231**, 185). A mixture of α-nitronaphthalene (20 g.) and ferric chloride

(0·5 g.) was liquefied on a water-bath, and bromine passed through it for 1 hour, hydrogen bromide being evolved. The product was poured into water, washed with sodium carbonate solution, and crystallised repeatedly from alcohol (charcoal), 4 g. of yellow needles, m. p. 121° (lit., 122·5°), being obtained (Found: N, 5·3; Br, 31·5. Calc. for $C_{10}H_6O_2NBr$: N, 5·6; Br, 31·7%).

6-Bromo-2-nitronaphthalene.—6-Bromo-β-naphthylamine, prepared by the method of Saunders and Hamilton (*J. Amer. Chem. Soc.*, 1932, **54**, 636), crystallised from glacial acetic acid in yellow plates, m. p. 206—207° (lit., 203°). After diazotisation it yielded *6-bromo-2-nitronaphthalene*, which crystallised from glacial acetic acid in brown-yellow needles, m. p. 190° (Found: N, 5·6; Br, 31·3. $C_{10}H_6O_2NBr$ requires N, 5·6; Br, 31·7%).

5 : *8-Dibromo-1-nitronaphthalene.*—This compound was prepared by a modification of Salkind's method (*Ber.*, 1931, **64**, 958), 1 : 4-dibromonaphthalene (19 g.) and concentrated nitric acid (110 c.c.) being stirred together at 65° for 4 hours. The precipitate obtained on cooling was crystallised repeatedly from glacial acetic acid, yielding 6·5 g. of pale yellow needles, m. p. 118° (lit., 116—117°).

4 : *6-Dibromo-5-*p*-toluenesulphonamidohydrindene.*—6-Bromo-5-aminohydrindene (Borsche and Bodenstein, *loc. cit.*) (18 g.) was dissolved in pyridine (50 c.c.), and *p*-toluenesulphonyl chloride (16·5 g.) added. The solution was boiled for 20 minutes and cooled, bromine (4·5 c.c.) added slowly, and the mixture kept overnight and poured into water. The sticky mass obtained solidified on trituration with cold alcohol (100 c.c.). 4 : *6-Dibromo-5-*p*-toluenesulphonamidohydrindene* (12 g.) crystallised from alcohol in colourless prisms, m. p. 199—200° (Found: Br, 36·7; S, 7·2. $C_{16}H_{15}O_2NBr_2S$ requires Br, 35·9; S, 7·2%).

4 : *6-Dibromo-5-aminohydrindene.*—The preceding compound (11 g.) was dissolved in warm concentrated sulphuric acid (120 c.c.), and the solution poured into a large volume of water, 4 : 6-dibromo-5-aminohydrindene separating. It crystallised from alcohol in colourless needles, m. p. 71° (Borsche and Bodenstein, *loc. cit.*, record 70°) (Found: Br, 53·8. Calc. for $C_9H_9NBr_2$: Br, 54·9%).

4-Bromo-5-aminohydrindene.—4 : 6-Dibromo-5-aminohydrindene (8 g.) was heated for 1 hour with alcohol (40 c.c.), concentrated hydrochloric acid (40 c.c.), and tin (8 g.). After 40 minutes the solution was filtered hot and poured into 2*N*-sodium hydroxide (250 c.c.), and the dark grey compound extracted with alcohol. Water was added to the alcoholic solution until it became milky; after 12 hours, long white needles (2 g.) of *4-bromo-5-aminohydrindene* separated, m. p. 50—51° (Found: N, 6·4; Br, 39·5. $C_9H_{10}NBr$ requires N, 6·6; Br, 37·6%). An oil was obtained by mixing the compound with 6-bromo-5-aminohydrindene, showing that the reduction had removed the 6-bromine atom.

4-Bromo-5-nitrohydrindene.—4-Bromo-5-aminohydrindene was converted into *4-bromo-5-nitrohydrindene* by the method used for preparing 3-bromo-2-nitronaphthalene (see above). The reaction mixture on steam distillation gave a pale yellow oil, but attempts to crystallise it met with no success. As in all cases of preparations of nitro-compounds by this method, the yield was exceedingly small, and we had little more than was sufficient for reactivity measurements and analysis (Found: N, 4·3; Br, 35·2. $C_9H_8O_2NBr$ requires N, 6·0; Br, 33·0%).

6-Bromo-5-nitrohydrindene.—6-Bromo-5-aminohydrindene (3·5 g.), m. p. 46—47° (Borsche and Bodenstein, *loc. cit.*, record 43°), was converted into *6-bromo-5-nitrohydrindene* by the method just mentioned. The reaction mixture was steam-distilled for 6 hours, and an oil obtained which was dissolved in ether–methyl alcohol. When the ether was allowed to evaporate at room temperature, the solution deposited 6-bromo-5-nitrohydrindene in yellow needles (0·5 g.), m. p. 42°. The compound was also prepared by standard methods from the nitro-5-acetamidohydrindene of Borsche and Bodenstein (*loc. cit.*) and purified by dissolving it in methyl alcohol and cooling the solution in a freezing mixture; m. p. 44—45°. The compound was shown to be identical with 6-bromo-5-nitrohydrindene by mixed m. p. determination and bromine reactivity (Found: N, 6·0; Br, 32·8. $C_9H_8O_2NBr$ requires N, 6·0; Br, 33·0%).

6-Bromo-7-nitrotetralin.—6-Acetyltetralin was converted into 6-acetamidotetralin by Scharwin's method (*Ber.*, 1902, **35**, 2513), but, as phosphorus pentachloride was found to be unsatisfactory for the Beckmann rearrangement involved, benzenesulphonyl chloride (cf. Blatt and Barnes, *J. Amer. Chem. Soc.*, 1934, **56**, 1150) was used. The oxime of 6-acetyltetralin (10 g.) was dissolved in pyridine (100 c.c.), and benzenesulphonyl chloride (12 c.c.) slowly added, the temperature being kept below 15°. After 3 hours the solution was poured into ice and dilute hydrochloric acid. After several hours 6-acetoamidotetralin separated and was crystallised from ligroin, m. p. 107°; yield, 6 g. If larger quantities of oxime were used, charring occurred and the yield diminished. The compound was nitrated (Schroeter, *Annalen*, 1921, **426**, 66), and

from the resulting 7-nitro-6-acetoamidotetralin 6-*bromo*-7-*nitrotetralin* was prepared by standard methods; it formed prisms from methyl alcohol, m. p. 53—54° (Found: N, 5·3; Br, 31·3. $C_{10}H_{10}O_2NBr$ requires N, 5·5; Br, 31·3%).

6-*Bromo-5-nitrotetralin*.—Prepared by the usual methods from 5-nitro-6-acetoamidotetralin (Schroeter, *loc. cit.*), this formed golden-yellow plates from alcohol, m. p. 103—104° (Vesely and Chudozilow, *Chem. Abs.*, 1925, **128**, 1056, record 101—102°) (Found: N, 5·7; Br, 30·6. Calc. for $C_{10}H_{10}O_2NBr$: N, 5·5; Br, 31·3%).

Quantitative Method.—The method followed was that of Salkind (*Ber.*, 1931, **64**, 289), as it was found to be suitable for small quantities of material. About 0·1 g. of the bromo(chloro)-compound was accurately weighed in a glass tube provided with a ground glass stopper. Piperidine (1 c.c.) was added, and the tube immersed in a thermostat at approximately 45°. After a definite interval of time the contents of the tube were washed into a separating funnel with water (50 c.c.), and the solution shaken with pure benzene, which removed coloured organic matter from the aqueous layer but no halogen. The aqueous layer was now almost colourless. The halogen present was determined by Volhard's method by titration with silver nitrate (*N*/50) and potassium thiocyanate (*N*/50), ferric alum being used as indicator. All determinations were done in duplicate.

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UNIVERSITY OF EDINBURGH. [*Received, May 4th, 1937.*]

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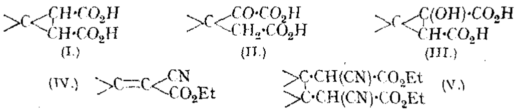
232. *The Dissociation Constants of Organic Acids. Part XVIII.* Some Cyclic 1 : 1-Diacetic Acids.*

By WILLIAM L. GERMAN and ARTHUR I. VOGEL.

OF the numerous methods that have been employed for the comparative study of the influence of substituents upon chemical properties with a view to the determination of qualitative values for valency-deflexion angles and also for throwing light upon the structure of ring systems, the two that have been applied to the largest number of substituents are those due to Thorpe and Ingold and their co-workers (J., 1915 *et seq.*) and to Vogel (J., 1928, 2014). The former depends *inter alia* upon (i) the stability of the *trans-spiro*-acid (I) towards hydrochloric acid of various concentrations at different temperatures, and (ii) the tautomeric change between keto-acids of the type (II) and their hydroxy-ring isomerides



(III). The latter method utilises the yield of the bimolecular compound (V), obtained by the reduction of the unsaturated cyano-ester (IV) with aluminium amalgam in moist ethereal solution, as a basis of comparison. The yields of (V) (compare J., 1931, 1796) for the substituents *cyclo*pentane and 3-methyl*cyclo*pentane are 13% and 13% respectively, and for *cyclo*hexane, and 2-,† 3-, and 4-methyl*cyclo*hexane the corresponding yields are 6, 2,† 6, and 4% respectively. These figures would suggest that there is no essential difference in the configurations of the *cyclo*pentane and 3-methyl*cyclo*pentane rings or between the unsubstituted *cyclo*hexane and the 3- and 4-methyl*cyclo*hexane rings and possibly also the 2-methyl*cyclo*hexane ring. Desai (J., 1932, 1065), employing the Thorpe–Ingold method, has found a remarkable similarity between the behaviour of the *cyclo*pentane and 3-

* The paper entitled "A New Series of Buffer Mixtures Covering the p_H Range 1 to 6" (*Analyst*, 1937, **62**, 271) is regarded as Part XVII.

† Oommen, Ph.D. Thesis, London, 1929.

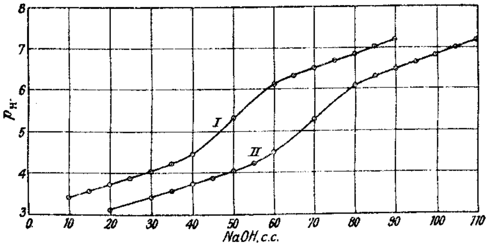
methyl*cyclo*pentane compounds, but serious differences were encountered between the *cyclo*hexane and the 3- and 4-methyl*cyclo*hexane compounds (J., 1932, 1053). Ives, Linstead, and Riley (J., 1932, 1093) suggest, as a result of their determinations of the *classical* primary dissociation constants of *cyclo*pentane-, *cyclo*hexane-, and 3- and 4-methyl*cyclo*hexane-1 : 1-diacetic acids, that the chemical tests employed by Desai are here "misleading if applied as a test for valency deflexion." The three authors state (*loc. cit.*) that their determinations of $K_{1\,\text{class.}}$ for these acids by conductivity "involve certain difficulties of calculation." A method for overcoming all these difficulties and which leads to values of the primary *thermodynamic* dissociation constants is described in Part XI of this series (J., 1935, 22). In view of the importance of the subject in connexion with the general question of the structure of simple and substituted *cyclo*pentane and *cyclo*hexane rings, measurements have been made of the *true* primary and secondary ionisation constants of the substituted 1 : 1-diacetic acids by potentiometric titration, and the distances between the carboxyl groups have been calculated by the methods of Bjerrum (*Z. physikal. Chem.*, 1923, **106**, 219) (B.) and of Gane and Ingold (J., 1931, 2153, 2160, 2180) (G. & I.). Our results, together with those of Gane and Ingold (J., 1931, 2158) and of Ives, Linstead, and Riley (I. L. & R.), are collected in the following table.

1 : 1-Diacetic acid.	$K_{1\,\text{therm.}}$ $\times 10^4$.	$K_{2\,\text{therm.}}$ $\times 10^8$.	r (B.) $\times 10^8$.	r (G. & I.) $\times 10^8$.	G. & I. K_1 ($\mu = 0$) $\times 10^4$.	G. & I. K_2 ($\mu = 0$) $\times 10^8$.	I. L. & R. $K_{1\,\text{class.}} \times 10^4$.
*cyclo*Pentane	1·60	17·0	1·30	3·38	1·66	25·8	1·76
3-Methyl*cyclo*pentane...	1·61	18·2	1·32	3·40	—	—	—
*cyclo*Hexane *	3·27	8·26	1·03	3·12	3·34	9·9	3·23
2-Methyl*cyclo*hexane ...	2·96	13·00	1·16	3·25	—	—	—
3-Methyl*cyclo*hexane ...	3·23	8·34	1·04	3·15	—	—	3·25
4-Methyl*cyclo*hexane ...	3·23	8·02	1·03	3·13	—	—	3·21

* Jones and Soper (J., 1936, 135) give $K_{1\,\text{therm.}} = 3{\cdot}25 \times 10^{-4}$ and $K_{2\,\text{therm.}} = 10{\cdot}85 \times 10^{-8}$.

The potentiometric titration curves are shown in Figs. 1 and 2; the abscissæ have been displaced for the different acids in order to avoid overlapping and to emphasise the similarities in the curves.

FIG. 1.



I. *cyclo*Pentane-1 : 1-diacetic acid. II. 3-Methyl*cyclo*pentane-1 : 1-diacetic acid.

Our results support the view that the substituted acids closely resemble the parent substances, and provide definite evidence for the current accepted conception of the strainless structure of the *cyclo*pentane and *cyclo*hexane rings.

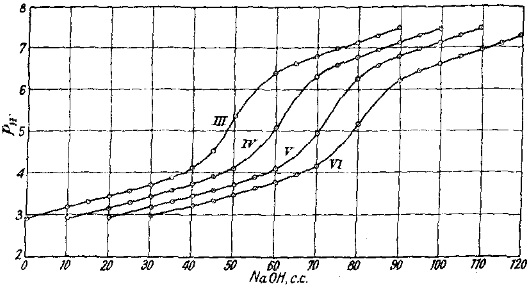
EXPERIMENTAL.

Preparation of Materials.—Full details of the preparation of all the acids, except 2-methyl*cyclo*hexane-1 : 1-diacetic acid, have been given by Vogel (J., 1934, 1760); only the methods of further purification are now indicated. All samples were dried in a vacuum desiccator over calcium chloride for several days before use.

cyclo*Pentane*-1 : 1-*diacetic acid.* Specimen I. A sample which had been recrystallised from dilute alcohol was crystallised from redistilled dioxan (b. p. 101—103·5°)–light petroleum

(b. p. 40—60°, AnalaR, sodium-dried), the separated solid well washed with sodium-dried light petroleum (b. p. 40—60°) to remove adhering dioxan, and then dried in a vacuum; m. p. 179°.

Fig. 2.



III. *cyclo*Hexane-1 : 1-diacetic acid. IV. 2-Methyl*cyclo*hexane-1 : 1-diacetic acid. V. 3-Methyl*cyclo*hexane-1 : 1-diacetic acid. VI. 4-Methyl*cyclo*hexane-1 : 1-diacetic acid.

Specimen II. This was purified through the anhydride and recrystallised from hot water; m. p. 178°.

cyclo*Hexane*-1 : 1-*diacetic acid*. Recrystallised from 80% alcohol; m. p. 181°.

2-*Methyl*cyclo*hexane*-1 : 1-*diacetic acid*. 400 C.c. of absolute alcohol were saturated with dry ammonia at − 5° during 5 hours and added to a mixture of 112 g. (1 mol.) of pure 2-methyl-*cyclo*hexanone, b. p. 164°/770 mm., and 226 g. (2 mols.) of ethyl cyanoacetate contained in a large (1500 c.c.) wide-mouthed glass-stoppered bottle. The whole was kept at 0° for 4 days and then at room temperature for 5 days. A small amount of solid (cyanoacetamide) separated; 2 litres of water were added (the separated solid dissolved), the whole extracted three times with ether, the aqueous layer acidified with hydrochloric acid (to methyl-red), and a further 200 c.c. of concentrated hydrochloric acid added. The separated dicyano-imide was collected after 24 hours and dried at 100° (29·3 g.). The crude substance had m. p. 243°, and m. p. 245° after recrystallisation from 50% alcohol (Kon and Thorpe, J., 1919, **115**, 694, give m. p. 245°). 58·4 G. of the finely-powdered dicyano-imide were dissolved in 120 c.c. of cold concentrated sulphuric acid, left for 24 hours, 112 c.c. of water cautiously added, and the whole boiled under reflux for 17 hours. The crude acid which had separated was filtered off after 48 hours, extracted with a saturated solution of sodium bicarbonate, the extract filtered, acidified with concentrated hydrochloric acid, and the solid collected after 24 hours (yield: 46·4 g. after drying at 100°). The acid was recrystallised successively from ether–benzene (2 : 1) and 50% alcohol; it had m. p. 152° (Kon and Thorpe, *loc. cit.*, give m. p. 148°).

3-*Methyl*cyclo*pentane*-1 : 1-*diacetic acid*. This was purified through the anhydride, and recrystallised from chloroform (AnalaR)–light petroleum (b. p. 40—60°, AnalaR, sodium-dried); m. p. 134—135°.

3-*Methyl*cyclo*hexane*-1 : 1-*diacetic acid*. Recrystallised from 50% alcohol; m. p. 142°.

4-*Methyl*cyclo*hexane*-1 : 1-*diacetic acid*. Recrystallised from 50% alcohol; m. p. 160°.

General Technique and Apparatus.—This has already been described (J., 1935, 912, 1628; *J. Amer. Chem. Soc.*, 1936, **58**, 1546; *Phil. Mag.*, 1936, **22**, 796). All measurements were carried out at 25° ± 0·01° with the quinhydrone electrode. Standardisation was effected before and after each titration against at least two independent 0·1*N*-calomel cells, and also against 0·05*M*-potassium hydrogen phthalate (the A.R. solid was specially purified for this purpose) and Walpole's standard acetate buffers (18°), appropriate allowance being made for the difference in temperature.

The results were computed as described for maleic acid (*Phil. Mag.*, *loc. cit.*), the large difference in magnitude between K_1 and K_2 permitting the independent evaluation of $K_{1\,\text{class.}}$ and $K_{2\,\text{class.}}$. All the results are collected in the following tables; the classical values are included to permit comparison with the data in the literature.

cyclo*Pentane*-1 : 1-*diacetic Acid* (M = 186·10).
Potentiometric titration of 100·00 *c.c. of* 0·005M-*acid against* 0·009950M-*sodium hydroxide solution.*

NaOH, c.c.	p_H.	$K_{1\,class.} \times 10^4$.	$\mu \times 10^3$.	$K_{1\,therm.} \times 10^4$.	NaOH, c.c.	p_H.	$K_{2\,class.} \times 10^7$.	$\mu \times 10^3$.	$K_{2\,therm.} \times 10^7$.
0·00	3·085	—	—	—	50·00	5·281	—	—	—
10·00	3·382	1·70	1·32	1·63	60·00	6·083	—	—	—
15·00	3·531	1·70	1·59	1·62	65·00	6·296	2·10	4·81	1·65
20·00	3·680	1·69	1·87	1·61	70·00	6·479	2·15	5·25	1·67
25·00	3·832	1·69	2·14	1·60	75·00	6·638	2·24	5·67	1·72
30·00	4·000	1·65	2·40	1·56	80·00	6·811	2·25	6·08	1·71
35·00	4·142	1·65	2·65	1·56	85·00	6·990	2·29	6·42	1·73
40·00	4·401	—	—	—	90·00	7·162	2·60	6·78	(1·95)
				Mean 1·60					Mean 1·70

3-*Methyl*cyclo*pentane*-1 : 1-*diacetic Acid* (M = 200·24).
Potentiometric titration of 100·00 *c.c. of* 0·005M-*acid against* 0·009950M-*sodium hydroxide solution.*

0·00	3·078	—	—	—	50·00	5·240	—	—	—
10·00	3·382	1·70	1·32	1·63	60·00	6·068	—	—	—
15·00	3·531	1·70	1·59	1·62	65·00	6·266	2·25	4·81	1·77
20·00	3·680	1·70	1·87	1·61	70·00	6·447	2·31	5·25	1·80
25·00	3·833	1·69	2·14	1·60	75·00	6·607	2·40	5·67	1·84
30·00	4·000	1·65	2·40	1·56	80·00	6·780	2·41	6·08	1·84
35·00	4·160	1·74	2·65	1·64	85·00	6·964	2·44	6·42	1·84
40·00	4·451	—	—	—	90·00	7·156	2·65	6·78	(1·99)
				Mean 1·61					Mean 1·82

cyclo*Hexane*-1 : 1-*diacetic Acid* (M = 200·24).
Potentiometric titration of 100·00 *c.c. of* 0·005M-*acid against* 0·009919M-*sodium hydroxide solution.*

0·00	2·914	—	—	—	50·00	5·377	—	—	—
10·00	3·178	3·49	1·57	3·34	60·00	6·376	—	—	—
15·00	3·306	3·45	1·79	3·29	65·00	6·600	1·036	4·79	0·814
20·00	3·437	3·44	2·02	3·27	70·00	6·787	1·040	5·23	0·808
25·00	3·553	3·45	2·25	3·27	75·00	6·939	1·097	5·65	0·844
30·00	3·721	3·45	2·48	3·26	80·00	7·108	1·109	6·04	0·834
35·00	3·890	3·41	2·65	3·21	85·00	7·301	1·094	6·41	0·828
40·00	4·129	3·26	2·91	(3·07)	90·00	7·482	—	—	—
				Mean 3·27					Mean 0·826

2-*Methyl*cyclo*hexane*-1 : 1-*diacetic Acid* (M = 214·25).
Potentiometric titration of 100·00 *c.c. of* 0·005M-*acid against* 0·009915M-*sodium hydroxide solution.*

0·00	2·970	—	—	—	50·00	5·176	—	—	—
10·00	3·208	3·11	1·52	2·98	60·00	6·183	—	—	—
15·00	3·338	3·10	1·76	2·96	65·00	6·415	1·60	4·79	1·26
20·00	3·467	3·13	1·99	2·98	70·00	6·596	1·64	5·24	1·28
25·00	3·606	3·13	2·23	2·96	75·00	6·761	1·68	5·65	1·29
30·00	3·758	3·12	2·47	2·95	80·00	6·926	1·72	6·06	1·31
35·00	3·927	3·14	2·69	2·96	85·00	7·093	1·81	6·40	1·36
40·00	4·134	—	—	—	90·00	7·288	1·95	6·76	(1·46)
				Mean 2·96					Mean 1·30

3-*Methyl*cyclo*hexane*-1 : 1-*diacetic Acid* (M = 214·25).
Potentiometric titration of 100·00 *c.c. of* 0·005M-*acid against* 0·009850M-*sodium hydroxide solution.*

0·00	2·931	—	—	—	50·00	5·058	—	—	—
10·00	3·168	(3·61)	—	—	60·00	6·313	—	—	—
15·00	3·300	3·49	1·79	3·32	65·00	6·562	1·07	4·73	0·845
20·00	3·438	3·39	2·01	3·22	70·00	6·756	1·07	5·23	0·832
25·00	3·574	3·39	2·24	3·20	75·00	6·932	1·07	5·59	0·824
30·00	3·719	3·40	2·47	3·22	80·00	7·100	1·08	5·98	0·825
35·00	3·890	3·38	2·68	3·19	85·00	7·271	1·11	6·35	0·843
40·00	4·090	3·48	2·90	3·28	90·00	7·435	—	—	—
				Mean 3·23					Mean 0·834

4-*Methyl*cyclo*hexane*-1 : 1-*diacetic Acid* (M = 214·25).
Potentiometric titration of 100·00 *c.c. of* 0·005M-*acid against* 0·009850M-*sodium hydroxide solution.*

0·00	2·941	—	—	—	50·00	4·937	—	—	—
10·00	3·184	3·38	1·55	3·23	60·00	6·257	1·23	4·20	(0·983)
15·00	3·213	3·34	1·77	3·19	65·00	6·584	1·11	4·73	0·801
20·00	3·438	3·38	2·01	3·21	70·00	6·772	1·04	5·23	0·805
25·00	3·577	3·36	2·24	3·18	75·00	6·946	1·04	5·59	0·799
30·00	3·715	3·45	2·47	3·26	80·00	7·113	1·05	5·98	0·800
35·00	3·884	3·44	2·68	3·24	85·00	7·291	1·06	6·35	0·804
40·00	4·078	3·60	2·90	(3·39)	90·00	7·492	—	—	—
				Mean 3·23					Mean 0·802

SUMMARY.

(1) The thermodynamic primary and secondary dissociation constants of *cyclo*pentane-, 3-methyl*cyclo*pentane-, *cyclo*hexane-, 2-methyl*cyclo*hexane-, 3-methyl*cyclo*hexane- and 4-methyl*cyclo*hexane-1 : 1-diacetic acids have been determined by potentiometric titration with the quinhydrone electrode at 25°.

(2) The intercarboxylic distances have been evaluated by the methods of Bjerrum and of Gane and Ingold. The results support the view that the *cyclo*pentane and *cyclo*hexane rings in these compounds are all strainless.

The authors' thanks are due to Mr. R. J. Tudor, M.Sc., A.I.C., for assistance in the preparation of the acids, and to the Royal Society and Imperial Chemical Industries for grants.

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233. *The Absorption Spectrum of Bivalent Samarium.*

By F. D. S. BUTEMENT and H. TERREY.

ALL the rare earths have a characteristic valency of three, and the absorption spectra of compounds in which they are tervalent have been studied in great detail. Three of the rare earths, samarium, europium, and ytterbium, can also be bivalent, and the absorption spectrum of europous chloride solution in the visible region (McCoy, *J. Amer. Chem. Soc.*, 1936, **58**, 1577), and the reflection spectrum of ytterbous iodide (Ephraim, Jantsch, and Zapata, *Helv. Chim. Acta*, **1933**, **16**, 261) have been investigated. In the case of bivalent samarium, however, nothing is known except the statement that " the reflection spectrum of solid samarium dibromide apparently consists of a diffuse band throughout the visible bearing no resemblance whatever to the discrete bands characteristic of most trivalent rare earth salts " (Selwood, *J. Amer. Chem. Soc.*, 1934, **56**, 2393).

The atomic numbers of samarium and europium being 62 and 63, respectively, the ions Sm^{++} and Eu^{+++} both have 60 electrons; their electronic configurations should therefore be the same, and the ions should show a close similarity in properties depending on this configuration. One of these properties is the magnetic susceptibility, and it is known that the susceptibilities of the two ions in their compounds are almost equal (Selwood, *loc. cit.*; Klemm and Rockstroh, *Z. anorg. Chem.*, 1928, **176**, 181). Another such property is the absorption spectrum, and the object of this work was to investigate that of aqueous samarous chloride, and to see whether it showed any resemblance to that of compounds of tervalent europium. The data available on the absorption spectrum of europium compounds in the ultra-violet are not very concordant with regard to the relative intensities of the bands, and it was therefore decided to study the chloride solution to determine which of the bands are the most intense.

EXPERIMENTAL.

The samarous chloride was prepared by a method similar to that described by Matignon and Cazes (*Compt. rend.*, 1906, **142**, 83). A Pyrex boat containing hydrated samaric chloride was placed in a silica combustion tube surrounded by a tube furnace. A stream of dry hydrogen chloride at about 5 cm. of mercury pressure was passed through the tube, which was heated to 100°. After several hours, when nearly the whole of the water had been driven off, the temperature was slowly raised to 500°. The anhydrous chloride was transferred to an iron boat, in which it was fused in the current of gas at 800°. The hydrogen chloride was now replaced by hydrogen at atmospheric pressure, to reduce the tri- to di-chloride. Before entering the apparatus, the hydrogen (from a cylinder) was freed from all traces of moisture, oxygen, etc., by passage through a tube containing a small quantity of molten sodium heated to 120°. Any ferrous chloride formed owing to attack on the iron boat by the hydrogen chloride sublimed off at the high temperature, and did not contaminate the samarous chloride. After 12 hours, the tube was allowed to cool, and transferred to a Richards sampling box, in which the samarous chloride was removed and ground in an atmosphere of dry carbon dioxide,

Fig. 1.

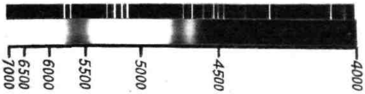


Fig. 2.

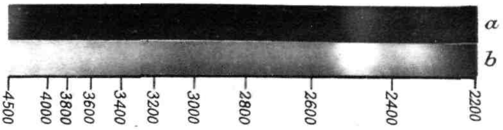
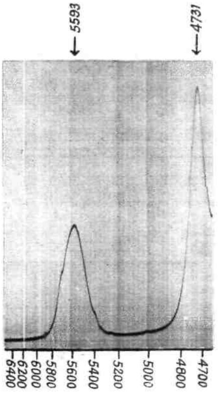


Fig. 3.



[*To face p.* 1112.

Fig. 4a.

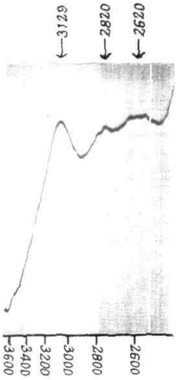


Fig. 4b.

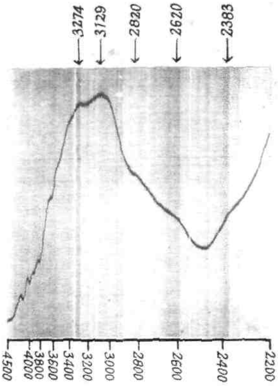


Fig. 4c.

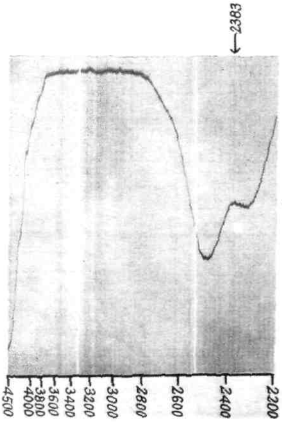
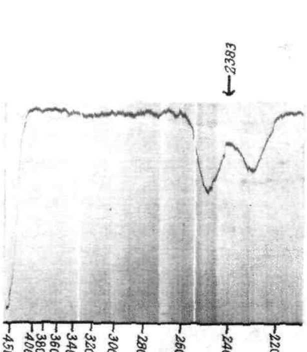


Fig. 4d.



being stored in a stoppered specimen tube. This substance could not be ground in the air owing to its rapid decomposition by oxygen or moisture.

Absorption Spectrum.—Samarous chloride is readily soluble in water, giving an intensely red solution. The colour rapidly fades owing to the decomposition $3SmCl_2 + 3H_2O \longrightarrow 2SmCl_3 + Sm(OH)_3 + 3H$, which is usually complete in 2—3 minutes. A quantity of samarous chloride, usually about 50 mg., was placed in a small silica centrifuge tube, 8 mm. in internal diameter and 7 cm. long. This was filled with ice-cold air-free water, and as rapidly as possible stoppered, shaken, and centrifuged to remove any turbidity produced by samaric hydroxide, and placed in front of the spectrograph slit, where it acted as an absorption cell.

For the visible spectrum the light source was a Pointolite lamp, and for the ultra-violet, a hydrogen discharge tube. Calibration was carried out in both cases with a copper arc. In all cases the spectrum of the solution was also recorded after complete decomposition had taken place. In no case was sufficient samarium trichloride produced to show its absorption spectrum. Hence it was not necessary to make any allowance for the trichloride present when spectra were taken with a partially decomposed solution of the dichloride. Photometer records of the spectra were taken with a Zeiss microphotometer in order to determine the positions of the absorption maxima.

For the absorption spectrum of europium trichloride, 10 mg. of Hilger's "H.S." europium oxide were dissolved in 1 c.c. of dilute hydrochloric acid, and the solution placed in a quartz-windowed absorption cell of 0·5 cm. internal thickness. Under these conditions only the more important absorption bands are visible in the photographs. These are listed in the table, the wave-lengths being those given by Prandtl and Scheiner (*Z. anorg. Chem.*, **1934**, **220**, 112).

Results.—Fig. 1 shows the absorption spectrum of samarous chloride in the visible region. There are two well-defined bands with maxima at 5593 and 4731 A., and a region of continuous absorption beginning about 4500 A. and extending into the ultra-violet. Fig. 3 shows the photometer record.

Fig. 2 shows the ultra-violet region; the spectrum *a*, taken with a concentrated solution, shows the region of continuous absorption, which began in the visible, extending to about 2600 A. There is also a band with maximum at 2383 A., and absorption of the extreme ultra-violet. Spectrum *b*, taken with a dilute solution, shows that the region of continuous absorption really consists of a number of overlapping broad bands.

Figs. 4 *a*, *b*, *c*, and *d* are the photometer records of spectra taken with solutions of increasing concentration; 4*a* shows the maximum at 3129 A. and two others at 2820 ± 50 and 2620 ± 50 A., the exact positions of which are difficult to determine; 4*b* shows the maximum at 3129 A. and irregularities in the curve due to maxima at 2820 and 2620, and also at 3274 and 2383 A.; 4*c* and 4*d* show the last maximum clearly, and the extension of the absorption region to 4300 A. suggests the existence of another band of longer wave-length than that at 3274 A.

The results obtained (in all cases the mean values from several photometer records of different plates) are given in the table. It will be seen that there is considerable resemblance between the spectra of bivalent samarium and tervalent europium. Owing to the greater nuclear charge in Eu^{+++} one would expect to find that its wave-lengths are slightly shorter than those for Sm^{++}, and this appears to be the case. However, although the bands of europium are extremely narrow, those of bivalent samarium are among the broadest shown by any rare-earth compound.

Absorption maxima, A.

Sm^{++}	5593		4731		(? *ca.* 4000)	3274	3129	2820 ± 50	2620 ± 50	2383
Eu^{+++}	5255	4656	4651	4647	3943	3179	2980	2867 2853	2513	—

SUMMARY.

The absorption spectrum of samarous chloride solution has been studied, and the positions of the main bands measured. It shows considerable similarity to that of europic chloride, as was to be expected theoretically.

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234. *The Associating Effect of the Hydrogen Atom. Part I. Amides and Sulphonamides.*

By HUBERT O. CHAPLIN and LOUIS HUNTER.

THE classical molecular-weight measurements of v. Auwers and his co-workers (for references see *Ber.*, 1937, **70**, 966) and of Meldrum and Turner (J., 1908, **93**, 876; 1910, **97**, 1605, 1805) provide ample evidence that amides and anilides are associated in solution. Replacement of both amide-hydrogen atoms, however, in the few cases in which measurements have been made (Meldrum and Turner, J., 1910, **97**, 1605; Mascarelli and Benati, *Gazzetta*, 1909, **39***B*, 642), appears to prevent association. It appeared of interest to find whether this is a general tendency, and if so, whether it is extended to the sulphonamides, which are themselves associated (v. Auwers, *Z. physikal. Chem.*, 1897, **23**, 449). The molecular weights of a series of *N*-substituted amides and sulphonamides have therefore been measured cryoscopically over a range of concentration, usually in benzene solution. The results clearly show that molecular association (as indicated by a steep association-concentration curve) is general in amides and sulphonamides possessing a free amide-hydrogen atom, but that replacement of both amide-hydrogen atoms effectively checks association (as indicated by a flat or gently sloped curve).

This dependence of association upon the presence of the amide-hydrogen atom clearly points to hydrogen-bond formation as the cause of association in the amides. The most probable type of hydrogen bond is that in which the hydrogen atom is shared between the nitrogen atom of one amide group and the oxygen atom of another. Whether this sharing is confined to two molecules or continues further, the molecular-weight evidence is insufficient to decide; but it appears probable that this mechanism of association has an intimate bearing on the tautomeric behaviour of amides and sulphonamides. In this connection it appeared vital to examine the case of the imino-ethers, which display no such tautomerism. It would seem from their superior volatility (see table) that these

	B. p.		B. p.
Ethylacetimino-ether	90—91°	*N*-Ethylacetamide ...	205°
Methylbenzimino-ether	96/13 mm.	*N*-Methylbenzamide ...	167/11 mm.; 291/765 mm.
Ethylbenzimino-ether	102/15 mm.	*N*-Ethylbenzamide ...	285/745 mm.

substances are molecularly simpler than the corresponding isomeric *N*-alkylamides. Determinations of the molecular weight of ethylacetimino-ether do indeed show that this substance is completely non-associated, though the isomeric *N*-ethylacetamide shows considerable association in benzene solution (see Fig. 1). This absence of association can only be due to the fact that the imino-ether, although it still possesses an imino-hydrogen atom, cannot utilise it to form a hydrogen bond because the oxygen atom, being ethereal and not ketonic, is available as a hydrogen acceptor only by becoming an oxonium ion. Such an alternative appears to be improbable in view of the small dipole moment of ethylacetimino-ether as compared with those of acetamide and its *N*-alkyl derivatives (Kumler and Porter, *J. Amer. Chem. Soc.*, 1934, **56**, 2549).

This evidence strongly favours the view that association of amides (and presumably also of sulphonamides) and their tautomeric behaviour are due to one and the same cause, *viz.*, the intermolecular sharing of hydrogen by resonance. The case is, indeed, similar to that already proposed for the diazoamino-compounds by one of us (this vol., p. **320**). The attached formulæ represent typical resonance open-chain (I) and cyclic (II) polymers, in which the number of individual molecules is purely arbitrary. It is suggested that the amides are resonance hybrids of extremes such as (I*a*) and (I*b*), or (II*a*) and (II*b*), or some variant of these. Dissociation of these polymers into the unimolecular form can thus follow two routes, giving either the amide or the isomeric imino-alcohol or both, according to the conditions imposed by the interacting reagent. The results of an *X*-ray analysis of fatty amides obtained by Henderson (*Proc. Roy. Soc. Edin.*, 1928, **48**, 20) and of isatin by Cox, Goodwin, and Wagstaff (*Proc. Roy. Soc.*, 1936, *A*, **157**, 399) would seem

FIG. 1.

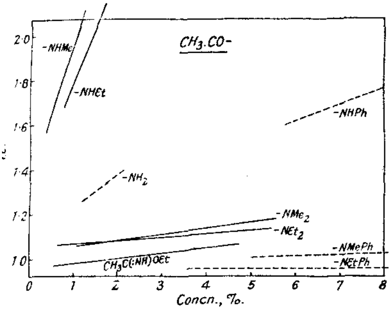
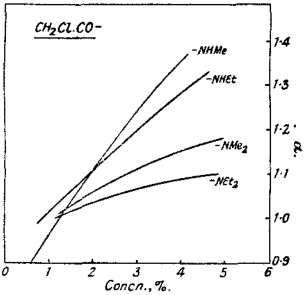


FIG. 2.



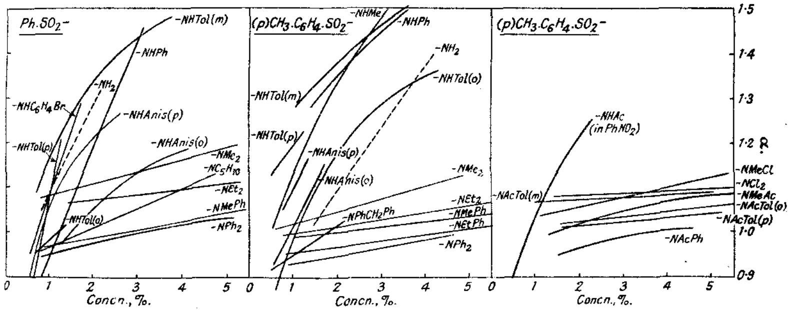


FIG. 3. FIG. 4. FIG. 5.

Data for CH_3·CO·NH_2 ebullioscopically in $CHCl_3$ } Meldrum and Turner, J., 1908, **93**, 882.
,, CH_3·CO·NHPh ,, ,, C_6H_6 }
,, CH_3·CO·NMePh ,, ,, ,, } *Idem*, J., 1910, **97**, 1612.
,, CH_3·CO·NEtPh ,, ,, ,, }
,, Ph·SO_2·NH_2 cryoscopically in $C_{10}H_8$ } v. Auwers, *Z. physikal. Chem.*, 1897, **23**, 449.
,, *p*-Tol·SO_2·NH_2 ,, ,, ,, }

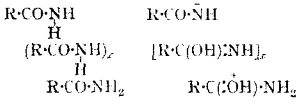
Broken lines.

CH_3·CO·NH_2 ebullioscopically in chloroform } Meldrum and Turner, J., 1908, **93**, 882.
CH_3·CO·NHPh ,, ,, benzene }
CH_3·CO·NMePh } ebullioscopically in benzene, Meldrum and Turner, J., 1910, **97**, 1612.
CH_3·CO·NEtPh }
Ph·SO_2·NH_2 } cryoscopically in naphthalene, v. Auwers, *Z. physikal. Chem.*, 1897, **23**, 449.
p-Tol·SO_2·NH_2 }

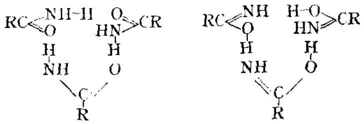
to favour a cyclic dimeride of type (II), at least for amides in the undissolved condition, and a recent investigation of the molecular weight of α-piperidone in benzene solution (Jenkins and Taylor, this vol., p. 495) indicates that with increasing concentration this substance approaches a dimeric state.

Reference to the tables given later will show that, in dilute solutions of amides and sulphonamides, the proportion of associated molecules is usually small. Resonance of the types suggested above, therefore, does not exclude other types, and it is evident that

the main contribution to the substantial dipole moments of acetamide and its alkyl derivatives (Kumler and Porter, *loc. cit.*) is due to resonance between $R{\cdot}C{<}^{O}_{NH_2}$ and $R{\cdot}C{\ll}^{\bar{O}}_{\overset{+}{N}H_2}$ (Pauling and Sherman, *J. Chem. Physics*, 1933, **1**, 606; Clow and Thompson, *Nature*, 1936, **138**, 802), a process which is necessarily confined to the unimolecular condition.

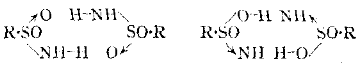


(*a.*) (I.) (*b.*)

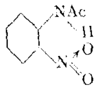


(*a.*) (II.) (*b.*)

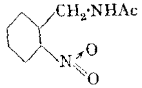
Formulæ similar to (I) and (II) may be adopted for the sulphonamides; *e.g.*, a cyclic dimeric polymer is depicted in (III).



(*a.*) (III.) (*b.*)



(IV.)



(V.)

In a recent review of physical measurements on the amides, v. Auwers (*loc. cit.*) decides in favour of a tautomeric equilibrium between the normal and the hydroxy-imino forms, at least for amides in the dissolved or liquid state. Most of the facts which he reviews can, in our opinion, be more satisfactorily interpreted in the light of a resonance phenomenon. In particular, reference may be made to the "cryoscopically normal" behaviour of numerous anilides possessing an ortho-substituent. Evidently in these compounds the tendency of the -CO·NH- group to accept and to donate hydrogen is checked by some intramolecular cause, and it is significant that in the majority the *o*-substituents are hydrogen-acceptors so constituted that six-membered chelation involving hydrogen is easily achieved. For example, whilst *o*-nitroacetanilide (IV) is not associated, its *m*-isomer is strongly associated; similarly, *o*-nitrobenzanilide is associated, but benzo-*o*-nitroanilide is not. In contrast to this, acet-*o*-nitrobenzylamide (V), where chelate ring-formation would not be anticipated, is as strongly associated as its *p*-isomer and as the parent acetobenzylamide (v. Auwers, *Z. physikal. Chem.*, 1897, **23**, 449).

In the following tables and curves, the association factors are calculated according to the ideal-solution laws, and are to be regarded merely as a qualitative indication of association. This probably accounts for some instances of apparent dissociation among the results. The abnormally high apparent molecular weights of *N*-methyl- and *N*-ethyl-acetamide (see Fig. 1) are probably attributable to the fact that under the prevailing experimental conditions the benzene solution is approaching the point at which separation into two layers occurs. Although no quantitative interpretation of the association factor is justified (Sidgwick, "The Electronic Theory of Valency," 1927, p. 149), some degree of association is reasonably certain.

A few results of other authors have been included in the figures (shown as broken lines, Figs. 1, 3, and 4), especially when, for reasons of solubility, the cryoscopic method in benzene proved unsuitable. Figures in parentheses indicate the normal molecular weight; *M* is the apparent molecular weight. Concentrations are given as g./100 g. of benzene; α is the association factor.

Derivatives of acetamide (Fig. 1).

	Concn.	*M.*	*a.*
N-Methylacetamide (73)	0·38	115·1	1·58
	0·795	133·6	1·83
	1·23	153·6	2·10
N-Ethylacetamide (87)	0·83	146·4	1·68
	1·81	189·8	2·18
N-Dimethylacetamide (87)	1·02	92·8	1·06
	2·27	95·6	1·10
	3·16	99·0	1·14
	4·03	99·9	1·15
	5·50	103·8	1·19
N-Diethylacetamide (115)	0·66	121·8	1·06
	1·41	121·9	1·06
	2·66	125·1	1·09
	4·39	127·2	1·11
	5·27	129·7	1·13
Ethylacetimino-ether (87)	0·63	84·1	0·97
	1·28	85·8	0·99
	2·58	89·2	1·03
	3·46	90·4	1·04
	4·68	92·5	1·06

Derivatives of chloroacetamide (Fig. 2).

	Concn.	*M.*	*a.*
N-Methylchloroacetamide (107·5)	0·57	96·3	0·90
	1·02	105·9	0·985
	1·46	112·9	1·05
	1·89	118·2	1·10
	3·10	133·2	1·24
	4·02	146·2	1·36
N-Dimethylchloroacetamide (121·5)	1·28	123·7	1·02
	2·89	135·0	1·11
	4·89	143·1	1·18
N-Ethylchloroacetamide (121·5)	0·74	117·3	0·97
	1·49	128·4	1·06
	2·40	139·7	1·15
	3·40	148·7	1·22
	4·58	160·2	1·32
N-Diethylchloroacetamide (149·5)	1·15	147·8	0·99
	2·47	156·7	1·05
	4·87	165·7	1·11

Derivatives of benzenesulphonamide (Fig. 3).

	Concn.	*M.*	*a.*
Benzenesulphonanilide (233)	0·68	199·3	0·86
	1·66	257·3	1·11
	2·59	307·0	1·32
	3·04	336·8	1·45
Benzenesulphon-*p*-bromoanilide (312)	0·64	298·0	0·96
	1·18	348·1	1·12
	1·75	398·1	1·28
Benzenesulphon-*o*-toluidide (247)	0·86	237·2	0·96
	1·28	250·4	1·01
Benzenesulphon-*m*-toluidide (247)	0·73	268·4	1·09
	1·61	316·4	1·28
	2·58	341·3	1·38
	3·76	365·4	1·48
Benzenesulphon-*p*-toluidide (247)	0·46	179·3	0·73
	0·87	247·6	1·00
	1·30	294·5	1·19
Benzenesulphon-*o*-anisidide (263)	1·34	258·2	0·98
	2·16	284·7	1·08
	3·05	299·8	1·14
	4·11	309·0	1·18
Benzenesulphon-*p*-anisidide (263)	0·64	235·4	0·90
	1·60	320·8	1·22
	2·46	331·3	1·26
Benzenesulphondimethylamide (185)	0·95	199·6	1·08
	1·89	198·9	1·075
	3·15	208·3	1·13
	4·23	213·5	1·15
	5·24	219·4	1·19
Benzenesulphondiethylamide (213)	1·51	228·1	1·07
	2·55	230·5	1·08
	4·21	233·6	1·10
	5·19	236·2	1·11
Benzenesulphonpiperidide (225)	0·78	214·9	0·96
	1·93	226·8	1·01
	3·15	236·7	1·05
	4·76	255·0	1·13
Benzenesulphonphenylmethylamide (247)	0·95	239·3	0·97
	2·10	250·2	1·01
	4·01	251·2	1·02
	5·25	260·8	1·06
	6·32	268·0	1·08
Benzenesulphondiphenylamide (309)	0·44	277·2	0·90
	1·10	300·7	0·97
	1·83	309·6	1·00
	3·52	320·2	1·04
	4·74	316·1	1·02

Derivatives of p-*toluenesulphonamide* (Fig. 4).

	Concn.	*M.*	*a.*
p-Toluenesulphonmethylamide (185)	0·56	188·7	1·02
	1·38	231·6	1·25
	2·22	255·7	1·38
	3·26	280·8	1·52
	3·97	295·3	1·60
p-Toluenesulphonanilide (247)	1·43	317·6	1·29
	2·59	350·5	1·42
	3·79	374·0	1·51
	4·64	387·3	1·57
p-Toluenesulphon-*o*-toluidide (261)	0·58	227·3	0·87
	1·23	293·5	1·13
	1·92	311·6	1·19
	2·57	327·8	1·26
	3·31	343·5	1·32
	4·23	353·6	1·36
p-Toluenesulphon-*m*-toluidide (261)	1·08	334·8	1·28
	1·82	358·3	1·37
	2·61	373·0	1·43
	3·59	390·0	1·49
p-Toluenesulphon-*p*-toluidide (261)	0·56	295·0	1·13
	1·21	320·0	1·23
p-Toluenesulphon-*o*-anisidide (277)	0·65	257·3	0·93
	1·09	295·8	1·07
	1·82	320·8	1·16
p-Toluenesulphon-*p*-anisidide (277)	0·83	291·4	1·05
	1·30	322·7	1·17
p-Toluenesulphondimethylamide (197)	0·67	199·1	1·01
	1·44	205·6	1·04
	2·07	204·9	1·04
	3·39	214·3	1·09
	4·87	221·8	1·13
p-Toluenesulphondiethylamide (227)	0·90	217·0	0·96
	2·56	230·0	1·01
	4·42	237·7	1·05
	5·97	242·4	1·07
p-Toluenesulphonphenylmethylamide (261)	1·10	251·6	0·96
	2·02	257·9	0·99
	4·81	269·8	1·03
	6·23	277·1	1·06
p-Toluenesulphonphenylethylamide (275)	0·91	261·5	0·95
	1·67	267·3	0·97
	2·98	270·3	0·98
	3·98	277·1	1·01
	5·80	281·3	1·02
p-Toluenesulphondiphenylamide (323)	0·93	291·0	0·90
	1·47	307·5	0·95
	2·50	315·6	0·98
	3·54	315·9	0·98
	4·55	321·1	0·99
p-*Toluenesulphonphenylbenzylamide* (337)	0·54	310·3	0·92
	1·37	325·8	0·97
	2·05	344·7	1·02

N-*Chloro- and* N-*acetyl derivatives of* p-*toluenesulphonamide* (Fig. 5).

	Concn.	*M.*	α.
p-Toluenesulphonmethylchloroamide (219·5)	1·16	227·1	1·04
	2·97	238·7	1·09
	4·42	244·4	1·11
	6·19	252·4	1·15
p-Toluenesulphondichloroamide (240)	1·50	258·4	1·08
	2·85	260·6	1·09
	3·83	260·6	1·09
	6·14	264·9	1·10
N-*Acetyl*-p-*toluenesulphonamide* (213)	0·41*	187·2	0·88
	1·41*	240·7	1·13
	2·17*	262·8	1·23
N-*Acetyl-p-toluenesulphonmethylamide* (227)	1·42	223·1	0·98
	2·62	237·5	1·05
	4·10	242·1	1·07
	5·48	245·1	1·08
N-*Acetyl*-p-*toluenesulphonanilide* (289)	1·59	274·5	0·95
	2·86	284·6	0·99
	4·48	292·7	1·01
N-*Acetyl*-p-*toluenesulphon*-o-*toluidide* (303)	1·77	308·1	1·02
	3·30	319·3	1·05
	6·01	323·2	1·07
N-*Acetyl*-p-*toluenesulphon*-m-*toluidide* (303)	1·06	324·2	1·07
	2·09	328·7	1·085
	3·57	323·5	1·07
	4·97	327·2	1·08
N-*Acetyl*-p-*toluenesulphon*-p-*toluidide* (303)	1·75	311·7	1·03
	2·97	306·9	1·01
	4·04	314·0	1·04
	5·10	319·3	1·05

* Concentrations in nitrobenzene.

EXPERIMENTAL.

Molecular weights were measured cryoscopically in benzene, except that for *N*-acetyl-*p*-toluenesulphonamide nitrobenzene was used. Materials were prepared and purified by usual methods, and the constants of known compounds are reported only when they differ from those recorded in the literature. They are as follows: ethylacetimino-ether, b. p. 90—91° (lit., 92—95°); *N*-diethylchloroacetamide, b. p. 105—107°/11 mm. (lit., 126·5—128·5°/21 mm.); benzenesulphon-*m*-toluidide, m. p. 97—98° (lit., 80°, 95°); benzenesulphondimethylamide, m. p. 51—52° (lit., 47—48°); *p*-toluenesulphon-*p*-toluidide, m. p. 119—120° (lit., 117—118°); *p*-toluenesulphondimethylamide, m. p. 80—81° (lit., 78—79°, 86—87°).

The following new compounds were prepared in the course of the investigation.

p-*Toluenesulphonphenylbenzylamide*, prepared by the action of *p*-toluenesulphonyl chloride on *N*-benzylaniline, formed white needles from alcohol, m. p. 139—140° (Found: N, 4·1; S, 9·7. $C_{20}H_{19}O_2NS$ requires N, 4·2; S, 9·5%).

N-*Acetyl*-p-*toluenesulphonamide*.—Equimolecular proportions of *p*-toluenesulphonamide and acetic anhydride were heated under reflux for 3 hours on an oil-bath at 140°. When the product was poured into cold water, the *acetyl* compound separated as a white crystalline powder, which was crystallised from alcohol. The substance is dimorphous, being obtained as stout rhombs from alcohol, but as needles from aqueous alcohol. Each form can be obtained from an alcoholic solution of the other by seeding with an appropriate crystal; both forms melt at 136—137°, and neither depresses the m. p. of the other. The substance is very sparingly soluble in water giving an acid reaction, decomposes carbonates, and behaves towards alkali as a monobasic acid with phenolphthalein as indicator (Found: N, 6·6; S, 15·0; equiv., 211·4. $C_9H_{11}O_3NS$ requires N, 6·6; S, 15·0%; equiv., 213). The molecular weight (see Fig. 5) of this substance was determined in nitrobenzene, as it was not sufficiently soluble in benzene.

The acetylation of the secondary sulphonamides is not so easily effected as that described above, and requires a higher temperature (180—200°) and the presence of freshly fused sodium acetate. The resulting compounds, having no tautomeric hydrogen, are neutral in reaction.

N-*Acetyl*-p-*toluenesulphonmethylamide* crystallises from alcohol in white prisms, m. p. 58—59° (Found: N, 6·1; S, 14·1. $C_{10}H_{13}O_3NS$ requires N, 6·2; S, 14·1%). N-*Acetyl*-p-*toluenesulphonanilide* crystallises from alcohol in white rhombs, m. p. 149—150° (Found: N, 4·8*; S, 11·2. $C_{15}H_{15}O_3NS$ requires N, 4·8; S, 11·1%). N-*Acetyl*-p-*toluenesulphon*-o-*toluidide* crystallises from alcohol in large clusters of white prisms, m. p. 100° (Found: N, 4·3; S, 10·9. $C_{16}H_{17}O_3NS$ requires N, 4·6; S, 10·6%). N-*Acetyl*-p-*toluenesulphon*-m-*toluidide* crystallises from alcohol in small white plates, m. p. 120° (Found: N, 4·5*; S, 10·6%). N-*Acetyl*-p-*toluenesulphon*-p-*toluidide* forms small white plates from alcohol, m. p. 135° (Found: N, 4·5*; S, 10·6%).

Our thanks are due to the Chemical Society for a grant, and to the British Association and the Leicestershire Education Committee for grants to one of us (H. O. C.).

UNIVERSITY COLLEGE, LEICESTER. [*Received, May 6th, 1937.*]

* The analyses denoted by an asterisk were carried out by Dr. G. Weiler.

235. *Rearrangement of the Alkylanilines. Part VIII. Migration of Large Groups.*

By W. J. Hickinbottom.

In earlier Parts (J., 1920, **117**, 103; 1927, 64; 1930, 1558, 1566; 1932, 2396) it was shown that monoalkylanilines, with *n*-alkyl groups from ethyl to butyl, smoothly underwent rearrangement on heating with suitable metal halides to form *p*-aminoalkylbenzenes. The work now described was undertaken with the object of determining the limits of this type of rearrangement. *n*-Amyl-, *n*-hexyl-, *n*-heptyl-, *n*-octyl-, *n*-dodecyl-, and cetyl-aniline were used for this purpose. When they are heated with anhydrous cobalt chloride or bromide at 212°, the alkyl group is transferred to the nucleus with no noticeable elimination as olefin. From the rearrangement of *n*-octylaniline, an amine is obtained which is identical with that established by Beran (*Ber.*, 1885, **18**, 132) to be *p*-amino-*n*-octylbenzene. The rearrangement of cetylaniline gives an amino-hexadecylbenzene, which from its m. p. and that of its acetyl derivative is probably identical with the aminocetylbenzene described by Krafft (*Ber.*, 1886, **19**, 2984) in which the alkyl group has the normal configuration. The orientation of the amino-group with respect to the cetyl has been found to be *para* by conversion of the amine into *p*-hydroxycetylbenzene (Krafft, *Ber.*, 1888, **21**, 3181; Hickinbottom, unpublished observation).

It is evident that when *n*-octyl or the cetyl group is transferred from the amino-group to the nucleus under the conditions described in this paper, it enters the *p*-position with respect to the amino-group and the configuration of the alkyl group is unchanged. It appears justifiable to assume from these examples that similar regularities occur in the rearrangements of other *n*-alkylanilines. This generalisation is rendered more probable by the proof (J., 1920, **117**, 110; 1930, 1558, 1566; 1932, 2396) that alkylanilines containing smaller alkyl groups such as *n*-propyl, *n*- and *iso*-butyl, and *iso*amyl suffer rearrangement under the influence of cobalt chloride or bromide without any alteration in the configuration of the alkyl group, which takes up a position in the nucleus *para* to the amino-group. Migration of the alkyl group to the *o*-position was not detected, although it is not improbable that it may occur to a limited extent.

More satisfactory evidence of the transference of the mobile group to a position other than *para* was observed with benzylaniline and with *cyclo*hexylaniline. Both these amines furnished not only the *p*-compound on rearrangement, but appreciable yields of isomeric amines in which the group is assumed to have entered the *o*-position. There was also good evidence of a similar type of rearrangement with *sec.*-octylaniline.

The most striking difference in behaviour of both *cyclo*hexylaniline and *sec.*-octylaniline as compared with the *n*-alkylanilines was the elimination of the greater part of the *cyclo*hexyl or the *sec.*-octyl group as unsaturated hydrocarbon. In this, they show a behaviour intermediate between that of the alkylaniline with *tert.*-alkyl groups and those with *n*-alkyl chains (this vol., p. 404).

Under the experimental conditions employed, the rearrangement is not confined to the formation of *o*- and *p*-aminoalkylbenzenes. Considerable amounts of products of higher boiling point are formed, consisting chiefly of alkylaminoalkylbenzenes $NHR{\cdot}C_6H_4R$. Benzylaniline, however, gives a higher-boiling fraction consisting largely of 2 : 4-*dibenzylaniline*.

The formation of such compounds may be caused by the preliminary formation of dialkylaniline and its subsequent rearrangement:

$$2NHR{\cdot}C_6H_5 \longrightarrow NH_2{\cdot}C_6H_5 + NR_2{\cdot}C_6H_5 \longrightarrow NHR{\cdot}C_6H_4R$$

Alternatively the reaction may be represented by assuming that the alkyl group during its migration from the nitrogen to the nucleus may attack unchanged alkylaniline with the formation of an alkylaminoalkylbenzene.

The validity of these hypotheses depends on the absence of dialkylaniline in the secondary amine used for the rearrangement. Special precautions were taken to ensure this (cf. J., 1930, 933). Furthermore, crystalline secondary amines, such as dodecylaniline and

cetylaniline, which can very easily be freed from tertiary amines, furnish alkylaminoalkylbenzenes in yields amounting to 40—55% of the weight of starting material. Benzylaniline, also easily purified, similarly yields a high proportion of 2 : 4-dibenzylaniline.

The simplest explanation of the formation of such products is a preliminary conversion of some of the secondary amine into aniline and a dialkylaniline. Support for this view is afforded by the detection of tertiary amines in the products of rearrangements promoted by metal salts (J., 1927, 64; unpublished observations). A similar reaction has been detected when the secondary amine is heated as its hydrogen halide salt (Beckmann and Correns, *Ber.*, 1922, **55**, 852), and the reverse change of dialkylaniline to monoalkylaniline occurs when dimethylaniline is heated with aniline hydrochloride (Frankland, Challenger, and Nicholls, J., 1919, **115**, 203).

During the course of this work the interesting observation was made that the hydrochlorides of the alkylaminoalkylbenzenes and to a less extent the hydrochlorides of the alkylanilines described in this paper, have abnormal solubilities; n-*heptylamino*-n-*heptylbenzene hydrochloride*, for example, is soluble in light petroleum (b. p. 40—60°). A more detailed description of the reactions of these substances is reserved for a future paper.

Experimental.

The general conditions for effecting the rearrangement consisted in heating the secondary amine with anhydrous cobalt chloride or bromide in a long tube having free access to the air at its upper end through an efficient guard-tube. The mixture was heated at a constant temperature by a vapour-bath. A sufficient length of the upper part of the tube was exposed to the air to serve as a condenser.

The product was isolated by treatment with aqueous ammonia, extraction with ether, and distillation of the extract under reduced pressure; three main fractions were generally obtained: (*a*) aniline; (*b*) a mixture of aminoalkylbenzene and unchanged secondary amine; (*c*) a fraction of higher b. p., which in most rearrangements consisted largely of an alkylaminoalkylbenzene. The residue, generally small, was not examined.

The aniline was identified by its b. p. and acetyl derivative. The major constituents of fraction (*b*) were separated by aqueous zinc chloride. The identity of the secondary amine was established by the comparison of suitable crystalline derivatives with authentic specimens. The aminoalkylbenzene from this fraction was generally purified through its sulphate or its acetyl derivative. The separation of the major constituent of fraction (*c*) in a pure state was usually achieved by repeated fractionation under reduced pressure, sometimes followed by crystallisation of its hydrochloride.

Rearrangement of n-*Amylaniline*.—*n*-Amylaniline was prepared by heating 87 g. of *n*-amyl bromide with 140 g. of aniline in a water-bath for 8 hours. The mixture was made alkaline, aniline removed as the sparingly soluble zincichloride (J., 1930, 992), and the unprecipitated amine isolated. Fractional distillation yielded 57 g. of *n*-amylaniline (b. p. 127—128°/16 mm.) and 14 g. of crude di-*n*-amylaniline (b. p. 260—280°). The *p*-toluenesulphonyl derivative of the former crystallised from alcohol in felted needles, m. p. 74° (v. Braun and Murjahn, *Ber.*, 1926, **59**, 1204, give m. p. 76—77°).

p-*Amino*-n-*amylbenzene*, b. p. 130°/16 mm., was a colourless liquid of not unpleasant odour (Found: C, 80·7; H, 10·5; N, 8·4. $C_{11}H_{17}N$ requires C, 80·9; H, 10·5; N, 8·6%). The *hydrochloride* separated as a felted mass of needles on cautious addition of hydrochloric acid to its aqueous solution (Found: HCl, 18·4. $C_{11}H_{17}N,HCl$ requires HCl, 18·3%). The sulphate was sparingly soluble in cold water, but crystallised from hot water in small white platelets. The *acetyl* derivative separated from aqueous alcohol in nacreous platelets, m. p. 101° (Found: C, 76·3; H, 9·2. $C_{13}H_{19}ON$ requires C, 76·0; H, 9·3%). The p-*toluenesulphonyl* derivative, prepared from the amine and *p*-toluenesulphonyl chloride in pyridine solution, separated from aqueous alcohol in long flattened needles, m. p. 68—69° (Found: C, 68·2; H, 7·1. $C_{18}H_{23}O_2NS$ requires C, 68·1; H, 7·3%).

After removal of *p*-amino-*n*-amylbenzene from the product of rearrangement, a fraction was collected at 150—190°/16 mm., which consisted largely of a secondary amine. Repeated fractionation concentrated the secondary amine in the fraction 180—185°/16 mm. as a viscous liquid having the general properties and reactions of the alkylaminoalkylbenzenes. It was no doubt amylaminoamylbenzene, but no analysis was made, as it could not be freed from a small quantity of associated amines.

TABLE I.

Amine.	Wt., g.	Promoter.	Wt., g.	*t*.	Hours.	Products, g. Unchanged amine.	NH_2Ph.	*p*-$NH_2\cdot C_6H_4R$.	*o*-$NH_2\cdot C_6H_4R$.	*p*-$NHR\cdot C_6H_4R$.
n-Amylaniline	5·90	$CoCl_2$	1·25	212°	13·0	2·82	0·91	2·52	—	0·60
	7·98		3·00	,,	16·75	1·38			—	2·93
n-Hexylaniline	5·76	$CoCl_2$	2·12	,,	13·46	1·07	0·40	2·68	—	2·19
	3·06		1·2	,,	14·37	0·65			—	1·85
	6·87		2·48	,,	23·66	1·23	0·82	1·83	—	2·10
n-Heptylaniline	6·92	$CoCl_2$	1·47	,,	17·80	not determined	0·57	1·40	—	3·20
	6·66		2·28		18·36	0·76			—	3·55
	6·64	$CoBr_2$	1·80	212	14·60	1·42	0·39	1·79	—	2·75
	6·38		2·97	,,	16·66	1·12	1·08	1·47	—	1·88
	5·77	$CoCl_2$	2·42	,,	20·66	0·79	0·52	1·61	—	1·78
n-Octylaniline	6·64	$CoCl_2$	1·72	,,	15·50	0·99	0·84	1·26	—	4·02
	6·50		1·81	,,	17·16	0·61			—	4·18
sec.-Octylaniline *	16·86	$CoBr_2$	6·36	,,	24·75	1·92	3·82	0·90		—
Dodecylaniline	9·72	$CoCl_2$	2·83	247	20·66	0·62	0·65	3·76	—	4·05
	8·12		2·6	212	23·5	0·77	0·69	1·75	—	4·49
Cetylaniline	6·38	$CoCl_2$	4·55	,,	20·55	0·54	not determined	1·23	—	3·20
	4·90		6·43		22	0·69	0·15	1·13	—	2·49
*cyclo*Hexylaniline †	21·2	$CoCl_2$	8·75	247	25·5	0·10	5·70	2·71	0·79	—
Benzylaniline ‡	15·3	$CoCl_2$	5·7	,,	15·8	0·38	1·50	4·05	0·83	0·21

* 4·91 G. of octene obtained, and 1·21 g. of a higher-boiling fraction (not further examined).

† 3·43 G. of *cyclo*hexene, 0·72 g. of a higher-boiling fraction, and a considerable amount of resin were also obtained.

‡ 4·2 G. of 2 : 4-dibenzylaniline isolated from the product.

Rearrangement of n-*Hexylaniline*.—*n*-Hexylaniline was prepared by heating aniline (100 g.) with *n*-hexyl iodide (50 g.) at 100°. After 6 hours, the product was made alkaline, and the bulk of the unchanged aniline removed by distillation. This recovered aniline (55 g.) together with an additional quantity (25 g.) was heated with a further amount of *n*-hexyl iodide (43 g.). The product was treated as described above, and the crude hexylaniline from both preparations combined. Repeated fractional distillation yielded n-*hexylaniline* (64 g.; 82%) as a colourless refractive liquid with a not very pleasant odour, b. p. 158°/28 mm. (Found : C, 81·3; H, 11·1; N, 7·8. $C_{12}H_{19}N$ requires C, 81·3; H, 10·8; N, 7·9%). It was further purified through its *hydrobromide*, which separated from concentrated alcoholic solution in large transparent tablets (Found : HBr, 31·2. $C_{12}H_{19}N,HBr$ requires HBr, 31·4%). The p-*toluenesulphonyl* derivative separated from alcohol in white well-shaped crystals, m. p. 67—68° (Found : C, 69·1; H, 8·1; N, 4·3. $C_{19}H_{25}O_2NS$ requires C, 68·9; H, 7·6; N, 4·2%), and the m-*nitrobenzenesulphonyl* derivative from aqueous alcohol in needles, m. p. 79—80° (Found : C, 59·4; H, 6·6. $C_{18}H_{22}O_4N_2S$ requires C, 59·7; H, 6·1%).

p-*Amino*-n-*hexylbenzene*, b. p. 146—148°/17 mm. (Found : C, 81·3; H, 11·1; N, 7·9. $C_{12}H_{19}N$ requires C, 81·3; H, 10·8; N, 7·9%), yielded a *hydrochloride* easily soluble in water and precipitated from aqueous solution by dilute hydrochloric acid (Found : HCl, 17·0. $C_{12}H_{19}N,HCl$ requires HCl, 17·1%). The *sulphate* was sparingly soluble in water [Found : H_2SO_4, 21·3. $(C_{12}H_{19}N)_2,H_2SO_4$ requires H_2SO_4, 21·7%]. The *acetyl* derivative crystallised from aqueous alcohol in platelets, m. p. 91° (Found : C, 76·8; H, 9·9; N, 6·5. $C_{14}H_{21}ON$ requires C, 76·7; H, 9·7; N, 6·4%).

p-n-*Hexylamino*-n-*hexylbenzene* was a slightly viscous, pale yellow liquid, b. p. 203—204°/18 mm. (Found : C, 83·2; H, 12·0. $C_{18}H_{31}N$ requires C, 82·7; H, 12·0%). Its *hydrochloride* crystallised from light petroleum (b. p. 40—60°) containing a little ethyl acetate (Found : C, 72·4; N, 4·8; Cl, 12·3. $C_{18}H_{31}N,HCl$ requires C, 72·6; N, 4·7; Cl, 11·9%).

Rearrangement of n-*Heptylaniline*.—The product obtained by heating a mixture of aniline (200 g.) and *n*-heptyl iodide (135 g.) at 100° for 6 hours was basified and distilled to remove the

excess of aniline. Repeated fractionation of the residue furnished *n*-heptylaniline (73 g.) and crude di-*n*-heptylaniline (22 g.). A further purification of *n*-heptylaniline was effected through its hydrobromide. n-*Heptylaniline* was a liquid with a very faint straw-yellow tint, b. p. 160—161°/21 mm. (Found: C, 81·8; H, 11·4. $C_{13}H_{21}N$ requires C, 81·6; H, 11·1%). The *hydrobromide* was sparingly soluble in concentrated hydrobromic acid and easily soluble in alcohol; it crystallised well from alcohol–ether (Found: HBr, 29·8. $C_{13}H_{21}N$,HBr requires HBr, 29·7%). The p-*toluenesulphonyl* derivative crystallised from alcohol in white prismatic needles, m. p. 76° (Found: C, 69·7; H, 8·0; N, 4·3. $C_{20}H_{27}O_2NS$ requires C, 69·5; H, 7·9; N, 4·1%), and the m-*nitrobenzenesulphonyl* derivative in silky needles, m. p. 96° (Found: C, 61·0; H, 6·5. $C_{19}H_{24}O_4N_2S$ requires C, 60·6; H, 6·4%).

p-*Amino*-n-*heptylbenzene* was a very pale yellow liquid, b. p. 159°/18 mm. (Found: C, 81·3; H, 10·8. $C_{13}H_{21}N$ requires C, 81·6; H, 11·1%). The *hydrochloride* crystallised from dilute hydrochloric acid in white needles (Found: HCl, 15·8. $C_{13}H_{21}N$,HCl requires HCl, 16·0%). The *acetyl* derivative was obtained in white flattened needles, m. p. 91—92°, from aqueous alcohol (Found: C, 77·2; H, 10·1; N, 6·1. $C_{15}H_{23}ON$ requires C, 77·2; H, 9·9; N, 6·0%).

p-n-*Heptylamino*-n-*heptylbenzene* was a somewhat viscous oil with a pale straw-yellow tint, b. p. 220—223°/18 mm. (Found: C, 83·3; H, 12·3. $C_{20}H_{35}N$ requires C, 83·0; H, 12·2%). The addition of aqueous sodium nitrite to a solution of the amine in glacial acetic acid yielded a yellow oily nitrosoamine which gave a pronounced Liebermann nitroso-test. The addition of concentrated hydrochloric acid to an ethereal solution of the amine gave the *hydrochloride* as a white crystalline cake with a tinge of green; after drying in a vacuum over potash, this crystallised from light petroleum (b. p. 40—60°) in small white nodular aggregates, m. p. 83—85° (Found: C, 73·8; H, 11·3; N, 4·3. $C_{20}H_{35}N$,HCl requires C, 73·7; H, 11·1; N, 4·3%). The hydrochloride was readily soluble in ether, benzene, chloroform, and alcohol, moderately soluble in light petroleum (b. p. 40—60°), and not easily soluble in hydrochloric acid.

The constitution of *p*-*n*-heptylamino-*n*-heptylbenzene was established by preparing it by refluxing *p*-amino-*n*-heptylbenzene (2·95 g.) and *n*-heptyl bromide (2·75 g.) for 24 hours in alcoholic solution containing suspended anhydrous sodium carbonate. The product, on fractionation, yielded *p*-*n*-heptylamino-*n*-heptylbenzene, b. p. 223°/18 mm., as a colourless oil, characterised by its hydrochloride, m. p. 83—85° after crystallisation from light petroleum (b. p. 40—60°), not depressed by the specimen described above.

Rearrangement of n-*Octylaniline*.—*n*-Octylaniline was prepared by the interaction of aniline (50 g.) and *n*-octyl iodide (25 g.) at 100° for 2 hours. The product was made alkaline, and the liberated amines fractionally distilled to separate the excess of aniline. After several distillations under reduced pressure, *n*-octylaniline was obtained as a colourless liquid (16 g.), b. p. 177—178°/25 mm. A small amount of a higher-boiling fraction was obtained and consisted presumably of di-*n*-octylaniline.

A second preparation from *n*-octyl bromide (23 g.) and aniline (50 g.) yielded 21 g. of *n*-octylaniline.

After a further purification through its hydrobromide, n-*octylaniline* was obtained as an almost colourless liquid, b. p. 177—178°/25 mm. (Found: C, 82·1; H, 11·4. $C_{14}H_{23}N$ requires C, 81·9; H, 11·3%). The p-*toluenesulphonyl* derivative crystallised from alcohol in fan-shaped clusters of needles, m. p. 42—43° (Found: N, 4·1. $C_{21}H_{29}O_2NS$ requires N, 3·9%).

p-Amino-*n*-octylbenzene was isolated as an almost colourless liquid, b. p. 170—172°/17 mm., which solidified on cooling; m. p. 19—21°. It was characterised by its acetyl derivative, m. p. 93—94°, benzoyl derivative, m. p. 115—116°, and p-*toluenesulphonyl* derivative, which formed needle-like crystals, m. p. 85—86°, from alcohol (Found: C, 70·4; H, 8·1; N, 4·3. $C_{21}H_{29}O_2NS$ requires C, 70·1; H, 8·1; N, 3·9%). Beran (*Ber.*, 1885, 18, 132) has described *p*-amino-*n*-octylbenzene, m. p. 19·5°, the acetyl derivative, m. p. 93°, and the benzoyl derivative, m. p. 117°.

p-n-*Octylamino*-n-*octylbenzene* distilled as a viscous, pale yellow liquid, b. p. 232—235°/14 mm., which solidified on cooling; m. p. 11—13° (Found: C, 83·3; H, 11·9. $C_{22}H_{39}N$ requires C, 83·3; H, 12·3%).

Rearrangement of sec.-*Octylaniline*.—*sec*.-Octylaniline was prepared from *sec*.-octyl bromide (50 g.) and aniline (100 g.) following the procedure described in the preceding preparations (compare J., 1935, 1282).

Anhydrous cobalt bromide (6·36 g.) and *sec*.-octylaniline (16·86 g.) were heated together at 212° for 24·75 hours in a wide vertical tube closed at the lower end; the upper end was attached to a downward condenser. Octene, b. p. 123—125°, distilled from the mixture and the last traces were removed by a gentle stream of carbon dioxide (yield, 4·97 g.). The non-volatile product yielded aniline (4·02 g.), unchanged *sec*.-octylaniline (1·92 g.), amino-*sec*.-octylbenzene (0·9 g.),

b. p. 165—170°/26 mm., and a fraction (1·21 g.), b. p. 180—230°/25 mm., from which a pure compound could not be isolated.

The amino-*sec.*-octylbenzene proved to be a mixture, for on acetylation it gave a slowly crystallising oil, from which p-*acetamido*-sec.-*octylbenzene* was isolated by fractionation, m. p. 84—85° (Found: C, 77·8; H, 10·4. $C_{16}H_{25}ON$ requires C, 77·7; H, 10·2%). Hydrolysis of this acetyl compound and benzoylation of the resulting amine yielded *p*-benzamido-*sec.*-octylbenzene, m. p. 107—109°, identical with that prepared by Beran's method (*loc. cit.*). The more soluble fractions from the purification of *p*-acetamido-*sec.*-octylbenzene were of lower m. p. and gave analytical figures approximating to those for acetamido-*sec.*-octylbenzene (Found: C, 77·8, 77·3; H, 10·5, 10·5%). It is evident that in this rearrangement a mixture of at least two isomeric amino-octylbenzenes is formed.

Rearrangement of Dodecylaniline.—*Dodecylaniline* was obtained by heating together aniline (50 g.) and dodecyl iodide (34 g.) at 120° for 3½ hours. Distillation of the product after basification yielded dodecylaniline, b. p. 212—214°/13 mm. (yield, 24·6 g.; 82%), and a residue (3·0 g.), presumably of didodecylaniline, distilling chiefly at 280—295°/12 mm. The former crystallised from methyl alcohol in needles, m. p. 27—28° (Found: C, 83·0; H, 12·2. $C_{18}H_{31}N$ requires C, 82·7; H, 12·0%). The *hydrochloride*, obtained by addition of concentrated hydrochloric acid to an ethereal solution of the amine, crystallised well from acetone or ethyl acetate; m. p. 88—91°. For analysis it was obtained from benzene–light petroleum in glistening scales (Found: C, 72·8; N, 4·6. $C_{18}H_{31}N,HCl$ requires C, 72·6; N, 4·7%). The p-*toluenesulphonyl* derivative crystallised from methyl alcohol in thin plates, m. p. 53—54° (Found: N, 3·5. $C_{25}H_{37}O_2NS$ requires N, 3·4%).

Rearrangement of dodecylaniline was effected by heating at 247° with anhydrous cobalt chloride. The product, after being freed from cobalt chloride, was distilled, yielding aniline as the first fraction and a mixture of p-*aminododecylbenzene* and dodecylaniline at 200—216°/13 mm. The residue (*A*) consisted of p-*dodecylaminododecylbenzene*.

p-Aminododecylbenzene was freed from associated dodecylaniline by treatment with dilute sulphuric acid and ether; it was recovered from the sparingly soluble sulphate and purified through its acetyl derivative. The ethereal and aqueous solutions from the separation of the sulphate of the primary amine yielded dodecylaniline on basification. *p*-Aminododecylbenzene crystallised from methyl alcohol in fan-shaped clusters of needles, m. p. 41—42° (Found: C, 83·0; H, 12·0. $C_{18}H_{31}N$ requires C, 82·7; H, 12·0%). p-*Acetamidododecylbenzene* separated from aqueous alcohol in nacreous platelets, m. p. 101—101·5° (Found: C, 79·3; H, 11·0; N, 4·6. $C_{20}H_{33}ON$ requires C, 79·1; H, 11·0; N, 4·6%).

p-Dodecylaminododecylbenzene was isolated by extraction of the residue (*A*) with boiling methyl alcohol; a small amount of dark resinous matter remained. *p*-Dodecylaminododecylbenzene separated from the methyl-alcoholic extract and a further amount was obtained by concentration of the filtrate. The product, after crystallisation, was obtained in small white clusters of needles, m. p. 48—49° (Found: C, 83·8; H, 12·8. $C_{30}H_{55}N$ requires C, 83·8; H, 12·9%). The identity of this compound was established by its preparation from *p*-aminododecylbenzene and dodecyl iodide. These two were heated together for 30 hours in alcoholic solution containing anhydrous sodium carbonate in suspension. After removal of the solvent and inorganic matter, the residue was crystallised from acetone; it had m. p. 48—49°, not depressed by the above specimen. A comparison of the hydrochlorides and nitrosoamines (mixed m. p., appearance) from both specimens further established the identity.

The *hydrochloride* was precipitated by the addition of concentrated hydrochloric acid to an ethereal solution of the amine. After drying, it separated from ethyl acetate as a white crystalline powder, m. p. 84—85° with previous softening from 82° (Found: C, 77·3; N, 3·2. $C_{30}H_{55}N,HCl$ requires C, 77·3; N, 3·0%). The *nitrosoamine* was precipitated as a yellowish oil by the addition of a solution of sodium nitrite in acetic acid containing a little water to a solution of the amine in glacial acetic acid. It solidified on cooling, and after being washed with water and crystallised from acetone formed very thin, narrow platelets, m. p. 40—41° (Found: C, 78·6; H, 12·0. $C_{30}H_{54}ON_2$ requires C, 78·5; H, 11·9%).

Rearrangement of Cetylaniline.—The cetylaniline was prepared by heating together cetyl iodide (50 g.) and aniline (30 g.) in a boiling water-bath for 3 hours. Distillation of the basified product yielded unchanged aniline, a small intermediate fraction, b. p. 180—240°/24 mm., and the main fraction, b. p. 255—285°/23 mm. (yield, 21·38 g.), consisting essentially of cetylaniline. A residue boiling above 285°/23 mm. was largely dicetylaniline. The pure cetylaniline boiled at 265—267°/23 mm. and solidified on cooling. It separated from methyl alcohol in long needles which slowly changed to aggregates of small needles, m. p. 41—43° (Fridau, *Annalen*, 1852,

83, 29, gives m. p. 42°). It was characterised by its *nitrosoamine*, which, prepared in the usual way, crystallised from methyl alcohol in pale yellow clusters of small needles, m. p. 40—41° (Found : C, 76·3; H, 11·0; N, 7·9. $C_{22}H_{38}ON_2$ requires C, 76·2; H, 11·1; N, 8·1%), easily soluble in light petroleum, ethyl acetate, chloroform or benzene, not readily so in cold ethyl or methyl alcohol. The p-*toluenesulphonyl* derivative crystallised from alcohol in very thin platelets, m. p. 64—65° (Found : C, 73·7; H, 10·0; N, 3·0. $C_{29}H_{45}O_2NS$ requires C, 73·8; H, 9·6; N, 3·0%).

The experimental procedure for the rearrangement of cetylaniline and the isolation of the products closely followed that described for dodecylaniline. Cetylaniline (6·38 g.) and anhydrous cobalt chloride (4·55 g.), heated together at 212° for 20·55 hours, gave a product which was separated by distillation into aniline, a fraction, b. p. 200—270°/26 mm. (1·83 g.), and a dark residue (*B*) (3·20 g.). The fraction, b. p. 200—270°/26 mm., was resolved by treatment with dilute sulphuric acid and ether into *p*-aminocetylbenzene (1·23 g.) and cetylaniline (0·54 g.).

p-Aminocetylbenzene crystallised from methyl alcohol in small needles, m. p. 51—52°, and formed an acetyl derivative, m. p. 102·5—103·5° (Found : C, 80·0; H, 11·5. Calc. for $C_{24}H_{41}ON$: C, 80·15; H, 11·5%). The p-*nitrobenzylidene* derivative crystallised from acetic acid as a yellow felted mass of needles, m. p. 71° (Found : N, 6·1. $C_{29}H_{42}O_2N_2$ requires N, 6·2%). For comparison, *p*-aminocetylbenzene was prepared by the reaction of cetyl alcohol, aniline, and zinc chloride. The main product was identical with that obtained in the rearrangement of cetylaniline, as shown by comparison (mixed m. p., appearance, and qualitative solubilities) of the free amines and the acetyl and the *p*-nitrobenzylidene derivatives.

The dark residue (*B*) was extracted repeatedly with boiling alcohol, leaving a small black residue. The extract deposited 2·15 g. of crystalline material, which after crystallisation from acetone and benzene was obtained as white bulky aggregates of needles, m. p. 62—63° (Found : C, 84·6, 84·8; H, 13·5, 12·9. $C_{38}H_{71}N$ requires C, 84·2; H, 13·2%). It was identified as p-*cetylaminocetylbenzene* by comparison (mixed m. p.) with a specimen prepared by heating cetyl iodide (3·5 g.), *p*-aminocetylbenzene (3·0 g.), and an excess of anhydrous sodium carbonate in absolute alcohol (20 c.c.) for 20 hours.

p-*Cetylphenylcetylnitrosoamine*, prepared by adding a solution of nitrous acid in glacial acetic acid to a solution of the amine in the same solvent, separated as a bulky yellow precipitate, which was purified by extraction with boiling light petroleum and crystallisation of the extract from acetone. It formed buff-coloured aggregates, m. p. 55° (Found : C, 80·1; H, 12·5. $C_{38}H_{70}ON_2$ requires C, 79·9; H, 12·4%), and gave a greenish-blue coloration when warmed with concentrated sulphuric acid and phenol.

Rearrangement of cyclo*Hexylaniline*.—Heating with anhydrous cobalt chloride at 212° was unsatisfactory, the greater part of the secondary amine being recovered after 17½ hours' heating; there was, however, a strong odour of *cyclo*hexane. Rearrangement at 247° gave better results. *cyclo*Hexylaniline (21·2 g.) and anhydrous cobalt chloride (8·75 g.) were heated together at 247° for 25½ hours in an apparatus similar to that used for the rearrangement of *sec.*-octylaniline. A distillate began to collect after 5—6 hours' heating and most of it was collected within 8 hours of the commencement of the heating. It amounted to 3·43 g., had b. p. 81—82°, was unsaturated, and had the characteristics of *cyclo*hexene. The product remaining in the decomposition tube, after basification and distillation, gave aniline (5·70 g.), a fraction, b. p. 140—175°/20 mm. (3·60 g.), a fraction, b. p. 175—235°/20 mm. (0·72 g.), and a thick residual varnish.

The fraction, b. p. 140—175°/20 mm., was resolved into *p*-amino*cyclo*hexylbenzene (2·71 g.), m. p. 46—48° (crude), *o*-amino*cyclo*hexylbenzene (0·7 g.), and *cyclo*hexylaniline (0·10 g.) (see J., 1932, 2648). The higher-boiling fraction (175—235°/20 mm.) contained a considerable proportion of a primary amine, but it has not yet been possible to isolate any pure product from it.

Rearrangement of Benzylaniline.—Anhydrous cobalt chloride (5·7 g.) and benzylaniline (15·3 g.) were heated together at 247° for 15·8 hours, a basic vapour being evolved. After the usual treatment the product yielded aniline (1·5 g.), a fraction (*C*), b. p. 110—200°/13 mm. (5·26 g.), a fraction (*D*), b. p. 200—260°/13 mm. (4·63 g.), and a dark resin-like mass of higher b. p. (3·27 g.).

The fraction (*C*), the greater part of which boiled at 180—185°/13 mm., was resolved, by treatment with dilute sulphuric acid, into unchanged benzylaniline (0·38 g.) and a mixture of *p*-aminodiphenylmethane and an isomeric primary amine which is provisionally assumed to be *o*-aminodiphenylmethane. These were separated by means of aqueous zinc chloride, which precipitated the bulk of the *p*-amine as a sparingly soluble zincichloride. The *o*-amine reacted only slightly.

p-Aminodiphenylmethane was purified through its acetyl derivative, which formed scales, m. p. 128°, from benzene and yielded the pure *p*-amine, m. p. 36—37°, on hydrolysis (Basler, *Ber.*, 1883, **16**, 2718, gives m. p. 34—35°). This amine was further characterised by its p-*nitrobenzylidene* derivative, golden-yellow flat needles from alcohol, m. p. 101—102° (Found: C, 76·0; H, 5·1; N, 8·9. $C_{20}H_{16}O_2N_2$ requires C, 75·9; H, 5·1; N, 8·9%), and by its *condensation product* with 2 : 4-dinitrochlorobenzene, brick red needles, m. p. 128—129° (Found: C, 65·1; H, 4·4; N, 12·4. $C_{19}H_{15}O_4N_3$ requires C, 65·3; H, 4·3; N, 12·0%). Reaction of the amine in light petroleum with phenylthiocarbimide gave p-*benzyl*-αβ-*diphenylthiourea*, which formed a crystalline powder from acetic acid, m. p. 148—149° (Found: C, 75·3; H, 6·1; N, 9·1. $C_{20}H_{18}N_2S$ requires C, 75·4; H, 5·7; N, 8·8%).

The crude *o*-aminodiphenylmethane on acetylation gave a product which after several crystallisations from alcohol and acetic acid melted at 126° (Found: C, 80·2; H, 6·6. Calc.: C, 80·0; H, 6·7%) (Carré, *Bull. Soc. chim.*, 1909, **5**, 121, describes *o*-acetamidodiphenylmethane, m. p. 135°). It strongly depressed the m. p. of the corresponding *p*-compound.

The fraction (*D*), b. p. 250—260°/13 mm., contained an appreciable proportion of a primary amine. This was precipitated as sulphate by the addition of a slight excess of dilute sulphuric acid, recovered, and converted into an *acetyl* derivative, which formed felted needles, m. p. 145—146°, from alcohol (Found: C, 83·9; H, 6·2; N, 4·4. $C_{22}H_{21}ON$ requires C, 83·8; H, 6·7; N, 4·4%). Hydrolysis of the acetyl derivative furnished pure 2 : 4-*dibenzylaniline*, which crystallised from light petroleum (b. p. 40—60°) in needles, m. p. 49—50° (Found: C, 88·2; H, 7·0; N, 5·2. $C_{20}H_{19}N$ requires C, 87·9; H, 7·0; N, 5·1%).

The filtrate from the precipitation of the sulphate was acidified more strongly and treated with sodium nitrite. A nitrosoamine (0·25 g.), presumably derived from benzylaminodiphenylmethane, was obtained, but nothing was isolated from it in a satisfactory state for analysis. After removal of the nitrosoamine, the aqueous acid solution was warmed till all diazo-compounds were decomposed and then made strongly alkaline; a tertiary amine (less than 0·02 g.) was liberated. The free amine was white; an aqueous solution of its hydrochloride had a strong yellow colour with a green fluorescence. It gave a white mercurichloride, m. p. 190—193° after softening from 185°. The amount available did not permit of further crystallisation or of mixed m. p. determinations (acridine mercurichloride has m. p. 234° and phenanthridine mercurichloride, m. p. 197°).

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University of Birmingham. [*Received, May 6th*, 1937.]

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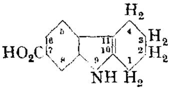
236. *Structural Problems in the Indole Group. Part II.*

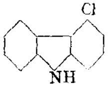
By R. C. G. Moggridge and S. G. P. Plant.

The investigation is a study of methods which might be used to remove the ambiguity attaching to the structures of several indole derivatives from the fact that Fischer's reaction can proceed in two alternative ways when applied to meta-substituted phenylhydrazones, and was undertaken also to obtain a more exact generalisation than has hitherto been possible regarding the course of the substitution reactions observed with 9-acyltetrahydrocarbazoles (numbering given in formula I). The tetrahydrocarbazole-5- and 7-carboxylic acids and the 5- and 7-chlorotetrahydrocarbazoles have been identified by the conversion of one of the isomers in each case into the corresponding 2-substituted carbazole. Nitration products obtained from various 9-acyl derivatives of 6-chloro-, 6-methyl-, and 3-methyl-tetrahydrocarbazole have all been shown to have the nitro-group in the 7-position, which can now be said, therefore, to be the normal position for the substituent in this series.

Reference has been made in Part I (J., 1936, 899) to the ambiguity which exists regarding the constitution of many indole derivatives as a result of the alternative positions which the cyclisation process may involve during their preparation from meta-substituted phenylhydrazones. Recent developments in various fields of carbazole chemistry have

made it possible to settle several structural problems of this type in the tetrahydrocarbazole series. Thus two acids, m. p. 287° and 210°, were obtained by Collar and Plant (J., 1926, 808) by the elimination of ammonia from *cyclo*hexanone-*m*-carboxyphenylhydrazone, and it has now been found that the dehydrogenation of the methyl ester of the former with palladised charcoal gives a product from which carbazole-2-carboxylic acid (I. G. Farbenind. Akt.-Ges., D.R.-P. 555,312; Plant and Williams, J., 1934, 1142) was obtained on hydrolysis. It follows that the compound, m. p. 287°, is tetrahydrocarbazole-7-carboxylic acid (I), and its isomer has the carboxyl group in the 5-position. Dehydrogenation of the methyl ester of tetrahydrocarbazole-8-carboxylic acid, obtained from *o*-hydrazinobenzoic acid, gave an almost quantitative yield of methyl carbazole-1-carboxylate, but a similar process applied to the acid itself resulted in simultaneous decarboxylation with the formation of carbazole.


(I.)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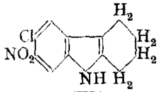
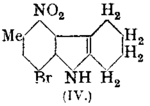

(III.)

It recently became necessary in connexion with other investigations in this laboratory to obtain a specimen of the hitherto unknown 4-chlorocarbazole (II) and it seemed probable that this could be done by dehydrogenating the products which might result from the application of Fischer's reaction to *cyclo*hexanone-*m*-chlorophenylhydrazone. The mixture obtained from the latter reaction has been found readily to yield 7-*chlorotetrahydrocarbazole* (*acetyl* compound, m. p. 111°), the constitution of which was established by its conversion into the well-known 2-chlorocarbazole (Ullmann, *Annalen*, 1904, **332**, 82) on boiling with sulphur in quinoline. The residue obtained after removal of as much of the 7-chloro-compound as possible gave 5-*chloro-9-acetyltetrahydrocarbazole*, m. p. 133°, on acetylation. The 5-chlorotetrahydrocarbazole obtained by hydrolysis of the latter has not been isolated as a solid, but the dehydrogenation of the acetyl derivative has given 4-*chloro-9-acetylcarbazole*, m. p. 126°, which was hydrolysed to the required 4-*chlorocarbazole*, m. p. 96°.

Substitution into the 9-acyltetrahydrocarbazoles presents some interesting features. It has long been known that nitration of several such derivatives involves the introduction of the substituent at either the 5- or the 7-position, both of which can be regarded as meta with respect to the *N*-acyl group, but a more exact generalisation has not been possible. For example, nitration of the 9-acetyl-, 9-benzoyl-, and 9-carbethoxy-derivatives of 6-chlorotetrahydrocarbazole, followed by hydrolysis of the products, has given in each case a substance, m. p. 184°, which was identical with one of the two compounds, m. p. 184° 162°, obtained by removal of ammonia from *cyclo*hexanone-4-chloro-3-nitrophenylhydrazone (Plant and Rosser, J., 1928, 2454). The compound, m. p. 162°, has now been reduced by the prolonged action of tin and alcoholic hydrochloric acid to 5-aminohexahydrocarbazole and then converted into 5-benzamido-9-benzoylhexahydrocarbazole, the preparation of an authentic specimen of which was described in Part I, and it follows that the substance is 6-chloro-5-nitrotetrahydrocarbazole; the isomer, m. p. 184°, resulting from the substitution reactions mentioned above has the nitro-group in the 7-position (III). The latter behaves quite differently on reduction under similar conditions; the chlorine is not removed and the product is 6-*chloro-7-aminotetrahydrocarbazole*. The greater stability of the chlorine is readily explained if the double bonds be considered as fixed in the positions shown in (III), but it is more difficult to account for the sluggishness with which the double bond in the 10 : 11-position is reduced. This cannot be entirely attributed to the presence of the chlorine atom, because 6-chlorotetrahydrocarbazole was easily converted by the same reagents into the corresponding *hexahydro*-compound.

The action of nitric acid on 9-acetyl-6-methyltetrahydrocarbazole has given a product which was converted on hydrolysis into a nitro-6-methyltetrahydrocarbazole, m. p. 181—182° (Manjunath and Plant, J., 1926, 2260). Three positions, the 5-, 7-, and 8-, are possible for the nitro-group. That the compound is not 8-*nitro-6-methyltetrahydrocarbazole* has

now been shown by the synthesis of this substance, which melts at 210°, from 3-nitro-*p*-tolylhydrazine and *cyclo*hexanone, and the possibility of the 5-position has been eliminated in the following manner. *8-Bromo-5-nitro-6-methyltetrahydrocarbazole* (IV) was prepared by an unambiguous route from 5-bromo-2-nitro-*p*-tolylhydrazine and *cyclo*hexanone, and converted by reduction into 5-amino-6-methylhexahydrocarbazole, in which there can be no doubt regarding the position of the amino-group. The latter is an oily base, but it readily gave a characteristic *dibenzoyl* derivative, m. p. 223°. Reduction of the nitro-compound, m. p. 181—182°, under similar conditions gave a different base, m. p. 109°, which must be *7-amino-6-methylhexahydrocarbazole*, the *dibenzoyl* derivative of which melted at 229°. It follows that the nitration process referred to has again resulted in substitution at the 7-position.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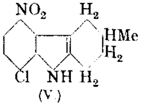
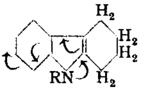

(V.)


(VI; R = Acyl.)

Another problem of the same type is presented by 3-methyltetrahydrocarbazole. Nitration of its 9-acetyl, 9-benzoyl, and 9-carbethoxy-derivatives has given compounds which on hydrolysis have all yielded a substance, m. p. 188°, identical with one of the two compounds, m. p. 188° and 175°, obtained synthetically from 4-methyl*cyclo*hexanone-*m*-nitrophenylhydrazone (Plant and Rosser, *loc. cit.*). Substitution must therefore involve either the 5- or the 7-position, and the former has been eliminated by the preparation of *8-chloro-5-nitro-3-methyltetrahydrocarbazole* (V) from 2-chloro-5-nitrophenylhydrazine and 4-methyl*cyclo*hexanone and its conversion by reduction during a restricted period into *5-amino-3-methyltetrahydrocarbazole*, m. p. 176°. The substitution product gave an *isomer*, m. p. 107°, under similar conditions and must therefore be the 7-nitro-compound. More prolonged reduction to the corresponding hexahydro-compounds was avoided in this case, since the products would be capable of existing in several stereoisomeric forms (Plant and Rosser, *loc. cit.*). It follows that the 7-position is that generally adopted by the substituent in the 9-acyltetrahydrocarbazole group, the mechanism of the process being explained as in (VI), in which the 10 : 11-double bond forms part of the route involved in the electromeric changes, as first pointed out by Robinson (see J., 1923, **123**, 684).

EXPERIMENTAL.

Dehydrogenation of Methyl Tetrahydrocarbazole-7-carboxylate.—The ester, m. p. 155° (Collar and Plant, *loc. cit.*), was mixed with 25% of its weight of palladised charcoal and heated at 280° for 5 hours in an atmosphere of hydrogen. The product was extracted with acetone, precipitated therefrom by the addition of water, and refluxed for 2 hours with aqueous alcoholic potassium hydroxide. When the resulting solution was diluted with water, filtered to remove an insoluble high-melting by-product, and then acidified, carbazole-2-carboxylic acid was precipitated in good yield. It melted at 322° (decomp.) after crystallisation from glacial acetic acid and its identity was confirmed by conversion into its ethyl ester, m. p. and mixed m. p. 184°.

Methyl tetrahydrocarbazole-8-carboxylate, when similarly treated for 14 hours at 300—320°, gave methyl carbazole-1-carboxylate in almost theoretical yield. Carbazole-3-carboxylic acid, identified by mixed m. p. with the acid of Plant and Williams (*loc. cit.*), was obtained in moderate yield, accompanied by a non-acidic high-melting substance, by the hydrolysis of the product obtained similarly from the 6-carboxylate after 5 hours at 280°, but attempts to obtain the unknown carbazole-4-carboxylic acid from methyl tetrahydrocarbazole-5-carboxylate, m. p. 93°, have been unsuccessful.

5- and 7-Chlorotetrahydrocarbazole.—A mixture of *m*-chlorophenylhydrazine (4 g.) and *cyclo*hexanone (3 c.c.) was heated on the steam-bath for a few minutes and then boiled for 15 minutes with dilute sulphuric acid (16%). Crystallisation of the product from methyl alcohol gave *7-chlorotetrahydrocarbazole*, which on recrystallisation from alcohol separated in colourless plates, m. p. 181° (Found: Cl, 16·9. $C_{12}H_{12}NCl$ requires Cl, 17·3%). It was converted into *7-chloro-9-acetyltetrahydrocarbazole*, colourless needles, m. p. 111°, from alcohol, by refluxing for an hour

with acetic anhydride and then shaking with an excess of water (Found : Cl, 14·2. $C_{14}H_{14}ONCl$ requires Cl, 14·3%). When the methyl-alcoholic mother-liquor was evaporated and the residue crystallised from glacial acetic acid, a further quantity of the 7-chloro-compound was isolated. The oily substance obtained by again evaporating the filtrate was acetylated as above and the product, on recrystallisation three times from alcohol, gave 5-*chloro*-9-*acetyltetrahydrocarbazole* in colourless needles, m. p. 133° (Found : Cl, 14·1%). The 5-chlorotetrahydrocarbazole obtained from this acetyl compound by hydrolysis with either alcoholic hydrogen chloride or aqueous alcoholic potassium hydroxide was an oil which could not be made to crystallise.

2- and 4-Chlorocarbazole.—A mixture of 7-chlorotetrahydrocarbazole (3·1 g.), sulphur (1 g.), and quinoline (25 c.c.) was refluxed for ½ hour, cooled, and poured into dilute hydrochloric acid. When the precipitate was dried on the steam-bath, distilled under reduced pressure with iron filings, and the distillate crystallised twice from alcohol, 2-chlorocarbazole was isolated in colourless prisms, m. p. 242°. It was identified by mixed m. p. with a specimen obtained from 5-chloro-2-nitrodiphenylamine as described by Ullmann (*loc. cit.*). The latter compound was prepared both by the method of Laubenheimer (*Ber.*, 1876, 9, 768) from aniline and 3 : 4-dinitrochlorobenzene, and by refluxing 2 : 4-dichloronitrobenzene with an excess of aniline and potassium acetate for an hour, removing the aniline in steam, and crystallising the residue from alcohol. These two alternative methods jointly prove the structure of the product. An attempt to dehydrogenate 7-chlorotetrahydrocarbazole with palladised charcoal in an atmosphere of hydrogen resulted in the elimination of the halogen.

When 5-chloro-9-acetyltetrahydrocarbazole was similarly oxidised with sulphur in quinoline and the product purified as before, 4-*chloro*-9-*acetylcarbazole*, colourless plates, m. p. 126°, from alcohol, was formed (Found : C, 68·9; H, 4·1. $C_{14}H_{10}ONCl$ requires C, 69·0; H, 4·1%). It was refluxed for ½ hour with aqueous alcoholic potassium hydroxide, and the solid obtained on dilution was extracted with hot alcohol. The residue from the evaporation of the filtered solution was crystallised from petroleum (b. p. 60—80°) and 4-*chlorocarbazole* was isolated in colourless needles, m. p. 96° (Found : C, 71·6; H, 4·4. $C_{12}H_8NCl$ requires C, 71·5; H, 4·0%).

Reduction of 6-Chloro-7-nitrotetrahydrocarbazole.—This substance (2·7 g.), m. p. 184° (Plant and Rosser, *loc. cit.*), was refluxed with granulated tin (27 g.), alcohol (55 c.c.), and concentrated hydrochloric acid (55 c.c.) for 15 hours, a further quantity of tin (13 g.) and hydrochloric acid (25 c.c.) being added after 7 hours. The mixture was made alkaline with sodium hydroxide, the alcohol removed in steam, and the product extracted with ether. After the extract had been dried with potassium carbonate and evaporated, 6-*chloro*-7-*aminotetrahydrocarbazole*, colourless plates, m. p. 166°, from alcohol, remained (Found : C, 65·3; H, 5·9. $C_{12}H_{13}N_2Cl$ requires C, 65·3; H, 5·9%).

The reduction of 6-chlorotetrahydrocarbazole (Borsche, Witte, and Bothe, *Annalen*, 1908, **359**, 53) under similar conditions gave 6-*chlorohexahydrocarbazole*, colourless needles, m. p. 67°, from petroleum (b. p. 60—80°) (Found : C, 69·4; H, 6·7. $C_{12}H_{14}NCl$ requires C, 69·4; H, 6·7%).

Reduction of 6-Chloro-5-nitrotetrahydrocarbazole.—This compound, m. p. 162° (Plant and Rosser, *loc. cit.*), was reduced with tin and alcoholic hydrochloric acid as above, but the product was an oil which could not be made to crystallise. It was therefore dissolved in acetone containing a little concentrated aqueous potassium hydroxide and shaken with benzoyl chloride. The addition of water then precipitated 5-benzamido-9-benzoylhexahydrocarbazole, colourless needles, m. p. 245°, from alcohol, which was identified by a mixed m. p. with an authentic specimen (Plant, J., 1936, 899).

8-Nitro-6-methyltetrahydrocarbazole.—After a solution of 3-nitro-*p*-tolylhydrazine (1·75 g.) and *cyclo*hexanone (1·1 c.c.) in alcohol had been boiled for 5 minutes, the corresponding hydrazone, scarlet plates, m. p. 97°, separated on cooling. When this was boiled for 15 minutes with water (200 c.c.) and concentrated sulphuric acid (40 c.c.), 8-*nitro*-6-*methyltetrahydrocarbazole*, brick-red plates, m. p. 210°, from glacial acetic acid, was obtained (Found : N, 12·2. $C_{13}H_{14}O_2N_2$ requires N, 12·2%).

5-Amino-6-methylhexahydrocarbazole.—5-Bromo-2-nitro-*p*-tolylhydrazine was prepared from the corresponding amine by diazotisation in concentrated hydrochloric acid and reduction with stannous chloride. The precipitate was shaken with much hot water, and the hydrazine isolated from the filtered solution by the addition of sodium acetate; it separated from alcohol in orange needles, m. p. 160°. After the hydrazine (9·6 g.) and *cyclo*hexanone (4·4 c.c.) had been boiled in alcohol for 5 minutes, the mixture treated with water (250 c.c.) and concentrated sulphuric acid (50 c.c.), and boiled again for 20 minutes, 8-*bromo*-5-*nitro*-6-*methyltetrahydrocarbazole*, orange prisms, m. p. 199°, from glacial acetic acid, was obtained (Found : Br, 26·0.

$C_{13}H_{13}O_2N_2Br$ requires Br, 25·9%). This (5·6 g.) was then reduced with tin and alcoholic hydrochloric acid, and the product isolated as described in the case of 6-chloro-7-nitrotetrahydrocarbazole. As the base could not be obtained crystalline, it was shaken in acetone with concentrated aqueous potassium hydroxide and benzoyl chloride (3·8 c.c.), and *5-benzamido-9-benzoyl-6-methylhexahydrocarbazole*, colourless needles, m. p. 223°, after crystallisation from benzene and then from alcohol, was isolated by precipitation with water (Found: C, 79·0; H, 6·4. $C_{27}H_{26}O_2N_2$ requires C, 79·0; H, 6·3%).

7-Amino-6-methylhexahydrocarbazole.—When the nitro-compound, m. p. 182°, described by Manjunath and Plant (*loc. cit.*) was reduced with tin and alcoholic hydrochloric acid as described above, *7-amino-6-methylhexahydrocarbazole*, colourless plates, m. p. 109°, from alcohol, was obtained (Found: C, 77·0; H, 8·8. $C_{13}H_{18}N_2$ requires C, 77·2; H, 8·9%). It was converted by benzoylation as before into *7-benzamido-9-benzoyl-6-methylhexahydrocarbazole*, diamond-shaped plates, m. p. 229°, after crystallisation from glacial acetic acid and then from *cyclo*hexanone (Found: C, 79·0; H, 6·4%). A mixed m. p. with the isomeric 5-benzamido-compound showed considerable depression.

When the reduction of the nitro-compound was suspended after ½ hour and the product isolated as before, *7-amino-6-methyltetrahydrocarbazole*, colourless plates, m. p. 175° (after softening at 169°), from alcohol, was obtained (Found: C, 77·8; H, 7·9. $C_{13}H_{16}N_2$ requires C, 78·0; H, 8·0%).

5- and 7-Amino-3-methyltetrahydrocarbazole.—When a mixture of 2-chloro-5-nitrophenylhydrazine (10 g.), 4-methyl*cyclo*hexanone (7·5 g.), and alcohol (25 c.c.) was boiled for 5 minutes, treated with aqueous sulphuric acid (250 c.c. of 27%), and boiled for a further 15 minutes, *8-chloro-5-nitro-3-methyltetrahydrocarbazole*, orange plates (4·0 g.), m. p. 195°, after crystallisation from glacial acetic acid and then from alcohol, was obtained (Found: Cl, 13·0. $C_{13}H_{13}O_2N_2Cl$ requires Cl, 13·4%). After this compound had been refluxed for ½ hour with tin and alcoholic hydrochloric acid and the mixture treated as in the analogous cases cited above, *5-amino-3-methyltetrahydrocarbazole*, colourless plates, m. p. 176°, from alcohol, was isolated (Found: C, 77·7; H, 8·0. $C_{13}H_{16}N_2$ requires C, 78·0; H, 8·0%).

When the "5(or 7)-nitro-3-methyltetrahydrocarbazole," m. p. 188°, of Plant and Rosser (*loc. cit.*) was similarly reduced during 20 minutes and the mixture treated as before, *7-amino-3-methyltetrahydrocarbazole*, colourless plates, m. p. 107°, from benzene–petroleum, was obtained (Found: C, 78·1; H, 8·0%).

The Dyson Perrins Laboratory, Oxford University. [*Received, June 17th*, 1937.]

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237. *The Decomposition of Aniline Nitrite.*

By J. Campbell Earl.

The nitrites of some aliphatic and alicyclic amines are remarkably stable substances and can be recrystallised from hot water without undergoing decomposition (cf. among others, Wallach, *Annalen*, 1907, **353**, 318). On heating in the dry state, decomposition usually takes place, but under reduced pressure certain amine nitrites may sublime in part unchanged (Ray and Datta, J., 1911, **99**, 1475).

The nitrites of aromatic amines are almost unknown, either in solution or in the solid state. Wallach prepared *as.-m*-xylidine nitrite and crystallised it from water: it was an unstable substance and soon changed into a red oil, the nature of which was not determined (*Annalen*, 1907, **353**, 321). Aniline nitrite was prepared by Earl and Hall (*J. and Proc. Roy. Soc. N.S.W.*, 1932, **66**, 453), and its identity established by its quantitative conversion into aniline and sodium nitrite on treatment immediately after preparation with sodium hydroxide solution.

Whether the amine nitrites as such play any part in the characteristic nitrous acid–amine reactions is not known with certainty, although Schmid (*Ber.*, 1937, **70**, 421) assigns a rôle to undissociated aniline nitrite in the diazotisation process. With a view to throwing light on this question a study has been undertaken of the changes undergone by aniline nitrite in the dry state on keeping.

When first prepared by evaporation under reduced pressure of its ethereal solution,

238. *The Thermal and Photochemical Decomposition of Acetyl Peroxide.*

By O. J. Walker and G. L. E. Wild.

In recent years the thermal decomposition of a number of acyl peroxides of the type $(R{\cdot}CO{\cdot}O)_2$ (R = alkyl or aryl radical) has been investigated (Wieland and co-workers, *Annalen*, 1930, **480**, 157; 1934, **513**, 93; Fichter and Buess, *Helv. Chim. Acta*, 1935, **18**, 445; Erlenmeyer and Schoenauer, *ibid.*, 1936, **19**, 338). When peroxides of this class are heated, either in the pure state or in solution, decomposition takes place according to the scheme (1). This process is in general accompanied by reactions of types (2*a*) and

$$(R{\cdot}CO{\cdot}O)_2 \longrightarrow R_2 + CO_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$(R{\cdot}CO{\cdot}O)_2 + R'H \begin{cases} \longrightarrow R{\cdot}CO{\cdot}OR' + RH + CO_2 \quad . \quad . \quad . \quad . \quad . \quad (2a) \\ \longrightarrow R{\cdot}CO{\cdot}OH + R'R + CO_2 \quad . \quad . \quad . \quad . \quad . \quad (2b) \end{cases}$$

(2*b*), where R'H may be a molecule of solvent, of peroxide, or of one of the decomposition products (cf. Gelissen and Hermans, *Ber.*, 1926, **59**, 662; this so-called RH scheme has been somewhat modified by Boeseken and Hermans, *Annalen*, 1935, **519**, 133; also Hermans, *Rec. trav. chim.*, 1935, **54**, 760). The whole decomposition process may, therefore, be very complex, and very little of the hydrocarbon R_2, which results from reaction (1), may appear amongst the final products.

The thermal decomposition of any particular acyl peroxide has usually been carried out in one of three ways: (*a*) Explosive decomposition, brought about by heating the peroxide in a steel bomb; (*b*) controlled decomposition, by gentle heating of the peroxide either alone or diluted with an inert material such as sand; (*c*) controlled decomposition of the peroxide in solution. Although a considerable amount of data has been accumulated regarding the nature of the products resulting from the thermal decomposition by these means of various acyl peroxides, very little is known about the mechanism of the decomposition process. The RH scheme (above) summarises in a convenient and comprehensive manner the different kinds of end-product of the thermal decomposition, but does not purport to represent the actual mechanism of the process. It has been applied almost entirely in discussing the behaviour of benzoyl and other aromatic peroxides. According to Hermans (*loc. cit.*, p. 767), aliphatic acyl peroxides decompose mainly according to reaction (1) but there does not exist much experimental evidence on the controlled decomposition of such peroxides (cf. Fichter, *Bull. Soc. chim.*, 1934, **1**, 1588).

Recently, we described some experiments on the decomposition of acetyl peroxide, $(CH_3{\cdot}CO{\cdot}O)_2$ (J., 1935, 207; cf. also Walker, J., 1928, 2040). It was originally considered that the results might have some bearing on the mechanism of the Kolbe electrosynthesis of ethane from acetates, since there is a possibility of the formation and decomposition of acetyl peroxide in this process, but it is doubtful whether definite conclusions can be obtained in this direction (see later). The study of the decomposition of acetyl peroxide is of more direct interest in the general problem of the thermal decomposition of acyl peroxides, especially of aliphatic peroxides, for which the validity of the RH scheme is not certain. We hoped that conditions might be found under which the decomposition of acetyl peroxide could be controlled so as to approximate as nearly as possible to reactions of type (1) or (2) alone. In this paper some experiments on the thermal decomposition of acetyl peroxide in the vapour state and in solution are described. No data are on record regarding the decomposition of any acyl peroxides in the vapour state.

In the case of a few peroxides the photodecomposition produced by their exposure to ultra-violet light at the ordinary temperature has been investigated, and it appears that the products correspond more closely to a reaction of type (1) (cf. Walker, *loc. cit.*, p. 2044; Fichter and Schnider, *Helv. Chim. Acta*, 1930, **13**, 1428). The earlier experiments

with acetyl peroxide were performed on the solid substance. The results of irradiating the peroxide in the liquid and the dissolved state are now reported.

EXPERIMENTAL.

1. *Thermal Decomposition of Acetyl Peroxide Vapour.*—The preparation of acetyl peroxide and the analysis of the gaseous products were carried out as previously described.

The decomposition of the peroxide vapour at 100° was performed in an all-glass apparatus (see Fig. 1). The solid peroxide, contained in a small tube, was introduced through *A* to the position shown at *C*, and surrounded by a freezing mixture. After being sealed off at *B*, the

FIG. 1.

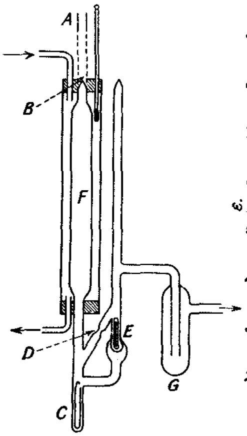
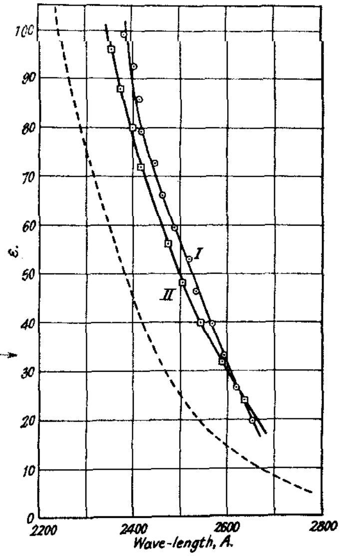


FIG. 2.

Absorption of acetyl peroxide in cyclohexane (I) *and in alcohol* (II).



whole apparatus was evacuated and then isolated from the pump by sealing at *D*. The peroxide in *C* was surrounded with a water-bath at 35°, and steam then passed through the jacket of the tube *F* containing peroxide vapour. The vapour pressure of liquid acetyl peroxide at 35° is of the order of a few mm. (owing to the slow decomposition of the liquid peroxide at this temperature, reliable measurements of the vapour pressure could not be made).

After sufficient time had elapsed, the heating was stopped, the tube *C* cooled with a freezing mixture, and the seal E broken with an electromagnet. The gaseous decomposition products were collected by means of a Töpler pump, the trap *G*, which was immersed in carbon dioxide–ether, preventing undecomposed peroxide vapour from entering the pump. In 6 hours 7·7 c.c. of gas (converted to N.T.P.) were collected. Similar results were obtained when the acetyl peroxide in *C* was kept solid at 18°, but owing to the lower vapour pressure of the solid, only 5·0 c.c. of gas were produced in 8½ hours.

The results of the gas analysis were as follows :—

Decomposition of acetyl peroxide vapour at 100° from	Composition of gas, % by vol.							
	CO_2.	O_2.	Unsat.	CO.	C_2H_6.	CH_4.	C_2H_6/CH_4.	CO_2/C_2H_6.
(*a*) Liquid at 35°	64·7	0·9	1·4	2·4	24·9	5·3	4·7 : 1	2·4 : 1
(*b*) Solid at 18°	66·0	0·8	1·2	3·2	24·4	4·4	5·5 : 1	2·5 : 1

The thermal decomposition of acetyl peroxide vapour at 100° takes place very largely according to equation (*1*) ($R = CH_3$). The C_2H_6/CH_4 ratio is about 5 : 1, and may be compared with the value of 0·3 : 1, found in the decomposition of the pure liquid peroxide at 90°, which was the highest value obtained previously from the thermal decomposition under any conditions.

The ratio of CO_2/C_2H_6 approaches the value of 2 : 1 required stoicheiometrically (the values given in the last column of the table have been calculated on the assumption that 1 vol. of carbon dioxide is formed for 1 vol. of methane, which seems probable). The small amount of methane produced indicates that reactions of type (2*a*) occur to a slight extent even in the vapour phase.

2. *Thermal Decomposition of Acetyl Peroxide in Solution.*—With aromatic acyl peroxides it has been well established that the solvent almost invariably takes part in the decomposition process in solution (cf. Hermans, *loc. cit.*, p. 760). The previous work on acetyl peroxide showed that decomposition in presence of a solvent always gave very much more methane than ethane in the gaseous products. This suggests, on the basis of the RH scheme, that appreciable reaction of the type (2*a*) ($R = CH_3$) occurs. The whole reaction process in solution is, however, undoubtedly complex, and without a more complete investigation and identification of all the reaction products formed with any given solvent, it is not possible to discuss the detailed application of the RH scheme to the case of acetyl peroxide solutions. In spite of the complexity of the decomposition process, it is possible to determine the order of the reaction in solution with respect to the acetyl peroxide decomposed. If the RH scheme applies, one would expect the rate of decomposition of the peroxide in presence of a large excess of solvent to appear unimolecular, and this was found to be the case.

Experiments were made in which the amount of peroxide left in the solution after definite time intervals was determined by titration. Toluene was chosen as solvent, since it has a sufficiently high b.p., and the thermal decomposition of acetyl peroxide in this solvent gives practically no reaction of type (1). The volume composition of the gaseous products obtained when a solution of 0·5 g. of acetyl peroxide in 100 c.c. of toluene is heated at 80° is : CO_2, 44·6; O_2, 1·4; CO, 2·0; CH_4, 50·7; C_2H_6, 1·4%; *i.e.*, almost entirely methane and carbon dioxide. At the ordinary temperature the solution of acetyl peroxide in toluene is quite stable. At 50° the rate of decomposition is too slow to allow of accurate measurements, but above 70° the decomposition becomes quite rapid, and the rate of reaction was measured at 80·0° and 87·3° ± 0·1°. Solutions of 1·25 g. of peroxide in 200 c.c. of toluene were used. The peroxide, dissolved in a small amount of toluene, was added to the main bulk of the solvent after it had attained the desired temperature. Portions of the solutions were removed at suitable intervals into cooled flasks, and the peroxide determined by titration of the iodine liberated from excess of potassium iodide with sodium thiosulphate solution in the usual manner. The results show that the reaction is of the first order with respect to the acetyl peroxide. In the following table the values of the percentage decomposition and of the unimolecular constant, *k*, at the different time intervals are recorded :

Temp.								
80·0°	*t* (mins.)	26	84	144	234	309	369	
	Decomp., %	8·8	30·6	46·7	65·3	75·2	79·0	
	$k \times 10^4$	(36·6)	43	44	45	45	42	Mean = 44
87·3	*t* (mins.)	29	59	95	144	203	256	
	Decomp., %	24·2	47·6	65·5	80·1	88·6	92·3	
	$k \times 10^4$	(96)	110	112	112	107	100	Mean = 108

The temperature coefficient of *k* is 3·3 for a rise of 10°, and the activation energy is 31 kg.-cals./mol.

3. *Photochemical Decomposition of Acetyl Peroxide.*—All the photodecomposition experiments were performed in a flat quartz cell fitted with a glass capillary delivery tube leading to a gas-collecting tube over mercury. The flat surface of the quartz cell (area about 12 cm.²) was exposed at 3—4 inches distance to the full light of a mercury vapour lamp of the horizontal

type, using a constant current of 2 amps. The cell was cooled by a jet of water flowing over it, the temperature being controlled to keep the peroxide solid or liquid as desired.

(a) *Solid acetyl peroxide.* In order to obtain data on the photodecomposition of the solid under conditions of exposure comparable with those for the decomposition of the liquid and dissolved peroxide, a few experiments were made in which the solid substance was irradiated at room temperature. About 30—40 c.c. of gas could be collected in ½ hour. The mean composition of the gas from several experiments is given in the following table, and confirms the earlier results in which the percentages of ethane and methane had been determined by explosion of the total hydrocarbon residue. In the present experiments the presence of these two hydrocarbons was checked more directly by the method of fractional condensation and separate explosion.

After removal of the undecomposed peroxide by means of dilute acetic acid solution, an insoluble gum was left which smelt strongly of esters. It was not analysed further.

Composition of the Gaseous Products from the Photodecomposition of Acetyl Peroxide.

		Composition, % by vol.						
State of peroxide.	Temp.	CO_2.	O_2.	Unsat.	CO.	C_2H_6.	CH_4.	C_2H_6/CH_4.
Solid	16—18°	67·4	0·4	1·0	1·3	25·0	5·1	4·9
Liquid	30	61·5	—	—	1·8	17·5	19·5	0·90
Solution in *cyclo*hexane	16—18	59·7	0·9	0·9	1·3	8·4	28·9	0·29
Solution in alcohol	16—18	43·8	0·5	0·7	1·6	4·6	48·6	0·09

(b) *Liquid acetyl peroxide.* The peroxide in the quartz cell was kept liquid by running a stream of water at 30° over the outside of the cell. When the mercury lamp was switched on, sufficient gas was evolved in 1 hour. The mean composition is given in the table. Although less ethane is evolved than from the solid peroxide, the C_2H_6/CH_4 ratio is 45 times greater than in the thermal decomposition of the liquid peroxide at the same temperature, for which the ratio is about 0·02 (Walker and Wild, *loc. cit.*, p. 208).

(c) *Acetyl peroxide in* cyclo*hexane.* Approximately 1% solutions of acetyl peroxide in pure *cyclo*hexane were irradiated in the water-cooled quartz cell at the ordinary temperature. A short induction period of about 2 minutes was always observed before gas evolution commenced, and slight gas evolution occurred after the lamp was switched off. Only the gas evolved during irradiation was collected. For every 0·1 g. of peroxide decomposed, about 38 c.c. of gaseous products were collected during 2 hours, the composition being shown in the table. Much less ethane is obtained than from the photodecomposition of the peroxide in the solid or the liquid state.

(d) *Acetyl peroxide in ethyl alcohol.* Absolute alcohol, redistilled over lime, was used. The evolution of gaseous products due to photodecomposition of the alcohol (cf. Berthelot and Gaudechon, *Compt. rend.*, 1911, **153**, 383) was negligible under the conditions of our experiments. With the solutions of the peroxide it was found that, after the light source was switched off, there was a considerable evolution of gas, which continued until all the peroxide had decomposed. In one case nearly a third of the total gas was obtained from this " dark " reaction. The composition of the main portion of the gas from a typical experiment is compared in the following table with that from the thermal decomposition of acetyl peroxide dissolved in alcohol (cf. Walker, *loc. cit.*, p. 2043):

	Composition, % by vol.		
	CO_2.	C_2H_6.	CH_4.
During irradiation	46·2	5·1	45·4
" Dark " reaction	45·3	5·0	46·8
Thermal reaction	50·7	1·6	45·7

For comparison with the other data, the mean composition of the gas evolved during the irradiation in several experiments is included in the previous table. In this case, also, the amount of ethane formed is very small.

(e) *Absorption spectrum of acetyl peroxide in solution.* The absorption spectrum of acetyl peroxide dissolved in *cyclo*hexane and in ethyl alcohol was measured by means of a Hilger rotating-sector photometer and medium quartz spectrograph, with a tungsten-steel spark as light source. In Fig. 2 the wave-length (in A.) is plotted against the molecular extinction coefficient ε, defined by $\varepsilon cd = \log I_0/I$ ($d = 0·99$ cm., c is in g.-mols./litre, and I_0 and I are the intensities of the incident and the transmitted light, respectively). The solutions used contained about 0·015 g.-mol. of peroxide per litre. A cell containing pure solvent was placed in the variable light beam of the photometer.

Acetyl peroxide has a continuous absorption band which commences at about 2800 A. and does not reach a maximum at the lowest wave-length investigated. As will be seen from Fig. 2, the absorption is very similar to that of hydrogen peroxide (broken curve, taken from Fergusson, Slotin, and Style, *Trans. Faraday Soc.*, 1936, **32**, 960). Both these substances contain the $\cdot O\cdot O\cdot$ link, and one may attribute the ultra-violet band of acetyl peroxide to this part of the molecule (cf. also Lederle and Rieche, *Ber.*, 1929, **62**, 2578).

There is the possibility that in the photochemical decomposition of acetyl peroxide the primary process consists of a dissociation $(CH_3{\cdot}CO{\cdot}O)_2 + h\nu \longrightarrow 2CH_3{\cdot}CO{\cdot}O{\cdot}$, followed by a further fission of the acetate radicals into carbon dioxide and methyl radicals, which could combine together to form ethane or react with surrounding solvent molecules to give methane as one of the products. Further discussion of these suggestions would be too speculative, however, at this stage, since the experimental work has, so far, been concerned mainly with exploring the conditions of decomposition.

CONCLUSION AND SUMMARY.

Acetyl peroxide is readily decomposed under a variety of conditions either by heating to temperatures up to 100° or by exposure to ultra-violet light. Comparison of the gaseous products obtained by both methods shows that they are qualitatively similar but quantitatively different. In general, ethane is formed more readily in the photochemical decomposition, but even in this process more methane than ethane is usually produced. The whole process in either case is rather involved, and it is probable that in both types of decomposition at least two simultaneous or consecutive reactions are taking place.

Reference may be made to the question whether acetyl peroxide is formed and then decomposed at the anode in the electrolysis of acetate solutions (cf. Glasstone and Hickling, J., 1936, 820; Fichter, *loc. cit.*; Höleman and Clusius, *Z. physikal. Chem.*, 1937, *B*, **35**, 261). The fact that acetyl peroxide can be made to decompose in a variety of ways to give a complex mixture of products makes it doubtful whether the results of such experiments have any direct bearing on the mechanism of the anodic process. It is uncertain whether any of the conditions of decomposition which we have described are at all comparable with the conditions existing at the surface of the anode during electrolysis. The observed similarity between the electrolytic products and those obtained from the decomposition of the peroxide under certain particular, but not necessarily comparable, conditions cannot, therefore, be used as evidence for the peroxide mechanism in the electrolytic oxidation, further discussion of which is beyond the scope of this paper.

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239. *Fused Carbon Rings. Part XII. A Simple Synthesis of Derivatives of Decalin from* cyclo*Hexanone, and Observations on* cyclo*Hexane*spiro*butyrolactone and Allied Compounds.*

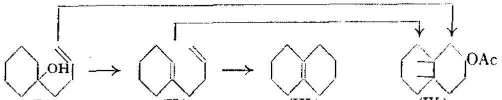
By R. P. LINSTEAD, ABEL BAO-LANG WANG, J. H. WILLIAMS,
and (in part) K. D. ERRINGTON.

IN recent communications (Hibbit and Linstead, J., 1936, 470; Hibbit, Linstead, and Millidge, *ibid.*, p. 476) it was shown that derivatives of decalin containing an angular methyl group could easily be obtained by the cyclisation of methyl-Δ^{γ}-butenyl*cyclo*hexanols, in which the alkyl groups were substituted on adjacent carbon atoms of the ring and the hydroxyl groups attached to either of these atoms. It was important to determine whether this method could be used for the synthesis of compounds not containing an angular methyl group, for it is known from the work of J. W. Cook and others that such a group facilitates cyclisation. Moreover, if unmethylated dicyclic compounds were obtainable by this process, it seemed probable that their configuration could be ascertained with certainty.

We have accordingly examined the action of a number of dehydrating agents on 1-Δ^{γ}-*butenyl*cyclo*hexanol* (I), which is easily prepared in one stage from *cyclo*hexanone. Oxalic acid at 130° yielded the monocyclic diene, probably 1-Δ^{γ}-*butenyl*cyclo*hexene* (II), which was unaffected by sodium and amyl alcohol. A mixture of phosphoric acid and phosphoric oxide dehydrated the alcohol to a mixture of diene and a dicyclic hydrocarbon. Cyclisation was completed by treatment of this mixture with phosphoric oxide at 140°. The dicyclic hydrocarbon obtained was an octalin, mainly the $\Delta^{9:10}$-isomeride, identical with that prepared from decalin by Nametkin and co-workers (*Ber.*, 1926, **59**, 370; 1929, **62**, 1570). The structure has been established with certainty by Hückel, Danneel, Schwartz, and Gercke (*Annalen*, 1929, **474**, 121). Our synthetic material yielded the same crystalline dibromide and blue nitrosochloride as obtained by the latter workers. On hydrogenation it gave the expected mixture of *cis*- and *trans*-decalins.

The position of the double bond is interesting. One would expect it in the Δ^1- or Δ^2-position, and in the corresponding 9-methyloctalin (in which the bridge position is impossible) the double bond is Δ^2 (Hibbit and Linstead; but see following paper). We find, however, that *trans*-Δ^2-octalin is readily isomerised to the $\Delta^{9:10}$-isomeride by heating with phosphoric oxide, and that *trans*-β-decalol yields the same substance when dehydrated under the conditions of cyclisation of butenyl*cyclo*hexanol. Hence the double bond is mobile and the $\Delta^{9:10}$-isomeride must be the final product, whatever the primary position taken by the double bond. It should be said that, although the hydrocarbons obtained in all these reactions give the solid derivatives of the $\Delta^{9:10}$-form and no acid oxidation products corresponding with other positions of the double bond, the physical constants vary to some extent and the presence of minor amounts of isomeric impurities is probable.

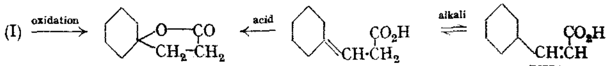
The next series of experiments was suggested by the work of Bertram and his collaborators on the cyclisation of geraniol to terpin hydrate and on the ready addition of acetic acid to terpenoid double bonds (*J. pr. Chem.*, 1894, **49**, 1, 194; 1900, **61**, 293). When 1-butenyl*cyclo*hexanol was treated with acetic acid containing a little acetic anhydride and sulphuric acid, it was partly converted into *cis*-β-decalyl acetate (IV), which on hydrolysis yielded the well-known form of *cis*-β-decalol of m. p. 104°. The diene (II) gave the same acetate and alcohol on treatment with a mixture of sulphuric and acetic acids.



(I.) (II.) (III.) (IV.)

The highest overall yield of decalol obtained from such cyclisations was only 25%, but the process represents a simple three-stage synthesis from *cyclo*hexanone and gives a product which is stereochemically nearly homogeneous.

Finally it was necessary to establish the fact that the double bond in the parent alcohol (I) was in the position shown and had not migrated during the preparation. This was proved by oxidation with permanganate, the alcohol yielding cyclo*hexane*spiro*butyrolactone* (V), the structure of which was established by its synthesis from β-cyclo*hexylidenepropionic acid* (VI).



(V.) (VI.) (VII.)

Examination of the literature on these substances and on the corresponding Δ^{α}-acid (β-*cyclo*hexylacrylic acid, VII) revealed a number of apparent abnormalities. Sircar (J., 1928, 54) prepared the Δ^{β}-acid (VI) by oxidising the corresponding unsaturated ketone, and the lactone (V) by condensing *cyclo*hexanealdehyde with malonic acid in the presence

of alcoholic diethylamine. Both products were described as liquids, the lactone boiling at 152—155°/15 mm., and the Δ^β-acid as having an odour resembling that of the lactone. It was also stated that long boiling of the lactone with alkali yielded the Δ^α-acid, but that the latter yielded no Δ^β-acid under the same conditions.

In the light of previous experience on the preparation and properties of unsaturated acids, many of these statements were open to question. We should expect: (i) The aldehyde to condense with malonic acid in the presence of a molar amount of diethylamine to yield the Δ^β-acid. (ii) The lactone to give with alkali the sodium salt of the γ-hydroxy-acid, which would not be dehydrated under the experimental conditions. (iii) A Δ^α-acid such as (VII) with a disubstituted γ-carbon atom to yield a considerable quantity of Δ^β-acid on boiling with alkali (compare J., 1932, 115). These substances have accordingly been reinvestigated with the following results.

The Δ^α-acid (VII), m. p. 59—60°, is readily prepared by condensing *cyclo*hexane-aldehyde with malonic acid in pyridine. If triethanolamine is used as condensing agent, the product is the Δ^β-acid (VI), m. p. 47—48°. This result falls into line with other similar condensations (Boxer and Linstead, J., 1931, 740; Linstead, Noble, and Boorman, J., 1933, 557). When the Δ^α-acid is boiled with alkali, it yields an equilibrium mixture of Δ^α- and Δ^β-acids containing 54% of the Δ^β-isomeride. The Δ^β-acid separated from this mixture by means of partial esterification (Eccott and Linstead, J., 1929, 2153) is identical with that prepared directly from the aldehyde. The Δ^β-acid is readily lactonised by cold 50% sulphuric acid to the *spiro*-lactone (V), m. p. 20°, identical with that prepared by the oxidation of butenyl*cyclo*hexanol. Like other lactones of similar structure (Boorman and Linstead, J., 1933, 580), the *spiro*-lactone is very little hydrolysed by boiling water. The pure lactone boils some 20° below the temperature recorded by Sircar and its odour is quite distinct from that of the Δ^β-acid. Sircar's "Δ^β-acid" and "lactone" therefore appear to have been mixtures of these substances, which would explain the abnormal reactions reported by him. It is difficult to avoid the lactonisation of Δ^β-acids of this type during their isolation, unless special precautions are taken.

These cyclic substances are therefore normal in their methods of preparation and properties, and closely resemble their acyclic analogues, such as Δ^α- and Δ^β-*iso*hexenoic acids and *iso*hexolactone, which contain two methyl groups in place of the ring.

EXPERIMENTAL.

A solution of 125 g. of Δ^γ-butenyl bromide (Linstead and Rydon, J., 1934, 1998) in 300 c.c. of dry ether was added during 4½ hours to 24 g. of magnesium, and after a further 2 hours' refluxing, a solution of 100 g. of *cyclo*hexanone in 200 c.c. of dry ether was added slowly. The mixture was refluxed overnight and decomposed with ammonium chloride solution, and the alcohol isolated by means of ether. After two distillations 58 g. (40%) of 1-Δ^γ-*butenyl*cyclo*hexanol* (I) were obtained, b. p. 95—96°/10 mm., $d_{4^\circ}^{14^\circ}$ 0·9333, $n_D^{14^\circ}$ 1·4814, $[R_L]_D$ 46·95 (calc., 47·24) (Found: C, 77·7; H, 11·4. $C_{10}H_{18}O$ requires C, 77·9; H, 11·7%).

Dehydration. 10 G. of the alcohol were refluxed with 10 g. of hydrated oxalic acid at 125—135° for 2 hours, and the residue distilled under reduced pressure. The distillate was dried with calcium chloride, refluxed for a further 2 hours with the residual anhydrous oxalic acid in the original flask, and again distilled. The distillate was washed with alkali, dried, and fractionally distilled, finally over sodium. 1-Δ^γ-*Butenyl*-Δ^1-cyclo*hexene* (II) was a mobile liquid with the strong smell of a diene, b. p. 60—62°/10 mm., $d_{4^\circ}^{18^\circ}$ 0·8445, $n_D^{18^\circ}$ 1·4745, $[R_L]_D$ 45·42 (calc., F_2 45·25). Yield, 6·2 g. (Found: C, 87·9; H, 11·4. $C_{10}H_{16}$ requires C, 88·2; H, 11·8%).

A mixture of 10 g. of the alcohol, 10 g. of phosphoric oxide, and 50 c.c. of syrupy phosphoric acid was refluxed at 160° for 3 hours. The cooled product was poured into water and neutralised, and the hydrocarbon extracted with ether. 7·5 G. of a liquid were obtained, b. p. 69—72°/10 mm., $d_{4^\circ}^{16\cdot8^\circ}$ 0·8677, $n_D^{16\cdot8^\circ}$ 1·4813, $[R_L]_D$ 44·56. Titration with percamphoric acid in chloroform solution (Masson, *J. Amer. Chem. Soc.*, 1933, **55**, 347) gave a value of 1·31 double bonds per molecule. The mixture of hydrocarbons (7 g.) was accordingly refluxed for 3 hours at 140° with 3 g. of phosphoric oxide and worked up as before. The smell had then changed from that of the diene to a faint pleasant odour. The octalin (mainly III) had b. p. 71—72°/10 mm., and the other physical properties shown in the table below. Titration

with percamphoric acid showed 0·96 double bond (Found: C, 87·6; H, 11·8. Calc. for $C_{10}H_{16}$: C, 88·2; H, 11·8%). The dibromide formed small plates from light petroleum (charcoal), m. p. 161—162°; and the nitrosochloride, obtained in good yield, separated from ether in massive blue prisms, m. p. 90° (decomp.). No white nitrosochloride could be isolated. Pure $\Delta^{9:10}$-octalin gives a dibromide, m. p. 163—164°, and a blue nitrosochloride, m. p. 91° (Hückel, Danneel, Schwartz, and Gercke, *loc. cit.*).

The octalin was reduced over Adams's catalyst in absolute alcohol. The product, distilled over sodium, had b. p. 74—76°/12 mm., $d_{4°}^{16·2°}$ 0·8809, $n_{D}^{16·2°}$ 1·4813, corresponding to a mixture of decalins, mainly the *trans*-isomeride (compare Hückel *et al.*) (Found: C, 86·5; H, 13·0. Calc. for $C_{10}H_{18}$: C, 87·0; H, 13·0%). Oxidation of the octalin with aqueous permanganate gave no isolable quantity of solid acid.

$\Delta^{9:10}$-Octalin was obtained for comparison following Hückel by dehydrating *trans*-decalol with zinc chloride, and by the following methods. *trans*-β-Decalol was heated with phosphoric acid and anhydride exactly as described above for butenyl*cyclo*hexanol. Yield, 94% of octalin. *trans*-β-Decalol was dehydrated to *trans*-Δ^{2}-octalin by means of potassium hydrogen sulphate (Leroux, Hückel) and this was refluxed with phosphoric oxide as described above for the complete cyclisation of the diene. Yield, 65%. The physical properties of these three octalins are tabulated below together with those of pure regenerated $\Delta^{9:10}$-octalin (Hückel) and of the cyclisation product of butenyl*cyclo*hexanol.

Preparation.	$d_{4°}^{t°}$.	$n_{D}^{t°}$.	*t*.	$[R_L]_D$.
(1) $ZnCl_2$	0·9165	1·4930	17·8°	43·12
(2) P_2O_5	0·9160	1·4970	16·0	43·46
(3) Isomerised Δ^{2}-	0·9206	1·4943	17·8	43·01
(4) Pure $\Delta^{9:10}$-	0·9170	1·4996	20·0	43·64
(5) Cyclisation product	0·9060	1·4955	16·0	43·82

$[R_L]_D$, calc. for $C_{10}H_{16}$ $|\overline{=}_1$, 43·51.

The dibromides of samples (1), (2), and (3) melted after crystallisation at 162—163°, and the nitrosochlorides at 91—93°. The derivatives of the isomerised Δ^{2}-octalin (sample 3) were the least pure and a trace of a white nitrosochloride was isolated. Mixed m. p. determinations of the derivatives of (2), (3) and of the cyclisation product (5) with the corresponding derivatives of authentic $\Delta^{9:10}$-octalin (1) showed no depression.

Dehydration of butenyl*cyclo*hexanol with potassium hydrogen sulphate gave a poor yield of unsaturated hydrocarbon.

Synthesis of cis-β-*Decalol* [with K. D. Errington].—200 C.c. of glacial acetic acid were mixed with 20 c.c. of acetic anhydride and 20 c.c. of concentrated sulphuric acid. To 150 c.c. of this mixture at 0° were added, during ½ hour, 20 g. of butenyl*cyclo*hexanol. The mixture was kept at room temperature for 5 days, poured into water, and extracted with ether. The extract was washed with 5% aqueous potassium hydroxide until the washings were alkaline, and then with water. The residue after removal of the solvent had a strong odour of an ester. It was refluxed with 20% methyl-alcoholic potassium hydroxide for 3 hours and kept overnight. The bulk of the methyl alcohol was removed through a column, and the residue poured into water. The decalol, isolated by means of ether, boiled at 120—126°/11 mm. and rapidly solidified. 5 G., m. p. 94—97°, were obtained, which, after pressing on a porous tile and one crystallisation from light petroleum, melted at 104°, alone or admixed with authentic *cis*-β-decalol (Found: C, 77·3; H, 11·75. Calc. for $C_{10}H_{18}O$: C, 77·9; H, 11·75%).

10 C.c. of the diene (II) were shaken with 30 c.c. of a 5% solution of sulphuric acid in acetic acid for 24 hours and finally warmed at 70—80° for ½ hour. The product was worked up in the manner described above, but was distilled before hydrolysis. 3·5 G. of an unsaturated hydrocarbon, b. p. 66—68°/10 mm., were obtained and a fragmentary residue of ester remained. This was hydrolysed as described above and yielded 1·2 g. of *cis*-β-decalol, m. p. and mixed m. p. 104°.

cyclo*Hexane*spiro*butyrolactone and Allied Substances*.—7·2 G. of Δ^{γ}-butenyl*cyclo*hexanol were shaken for 6 hours at room temperature with 800 c.c. of 3% potassium permanganate solution. Sulphur dioxide was passed to clear the solution, which was then acidified and thoroughly extracted with ether. The extract yielded 3·8 g. of a colourless oil with a characteristic lactonic odour, b. p. 131—133°/10 mm. This slowly solidified; the pure material was obtained by pouring off liquid impurities. cyclo*Hexane*spiro*butyrolactone* melts at 20—20·5° and dissolves very slowly in caustic alkali (Found: C, 69·8; H, 9·2. $C_9H_{14}O_2$ requires C, 70·1; H, 9·1%).

*cyclo*Hexanealdehyde diethylacetal, obtained in 65% yield from *cyclo*hexylmagnesium chloride, gave 52% of the free aldehyde, b. p. 155—160°. A mixture of 10 g. of the aldehyde, 10 g. of malonic acid, and 13 g. of pyridine was kept for 5 days at room temperature and then heated on the steam-bath overnight. β-*cyclo*Hexylacrylic acid (VII) (compare Sircar, *loc. cit.*) was isolated in the usual manner, purified through sodium bicarbonate, and crystallised from light petroleum. Yield, 12 g.; m. p. 59—60° (Found: C, 70·0; H, 9·1; equiv., 153. Calc. for $C_9H_{14}O_2$: C, 70·1; H, 9·1%; equiv., 154).

A mixture of 10 g. of the aldehyde, 10 g. of malonic acid, and 20 g. of triethanolamine was kept for 5 days at room temperature and overnight on the steam-bath. The product was cooled to 0°, covered with a layer of ether, and cautiously acidified with ice-cold dilute sulphuric acid. These precautions were necessary to prevent lactonisation. The aqueous layer was further extracted with ether, and the organic acid extracted from the combined ethereal layer with aqueous sodium bicarbonate. Finally, the acid was again liberated with ice-cold sulphuric acid, and isolated by extraction with ether and distillation. B. p. 156—159°/16 mm.; yield, 5 g. β-cyclo*Hexylidenepropionic acid* slowly solidified and crystallised from a little light petroleum in large overlapping plates, resembling in its crystalline form and unpleasant smell other Δ^{β}-acids. M. p. 47—48° (Found: C, 69·9; H, 9·2; equiv., 152. $C_9H_{14}O_2$ requires C, 70·1; H, 9·1%; equiv., 154).

7·7 G. of the Δ^{α}-acid were boiled for 12 hours with 40% aqueous potassium hydroxide (30 c.c.), and the mixed acids isolated in the usual manner. The bulk of the product (6·1 g.) was partly esterified by standing with 12 c.c. of *N*-hydrochloric acid and 20 c.c. of alcohol. The mixture was separated into Δ^{α}-acid and Δ^{β}-ester in the usual way. The former (2·9 g.) melted at 57—59° without crystallisation. The latter (3·5 g.) boiled at 116—118°/18 mm. and on hydrolysis yielded 2·5 g. of Δ^{β}-acid. A reserved portion of the mixed acids (1·0 g.) had an equivalent of 152, showing that it was practically free from lactone. The iodine additions of this material (Linstead and May, J., 1927, 2565; time 12 minutes), of the two pure acids, and of known mixtures are shown below:

Δ^{α}-Acid, %	100	48	39	0 (Δ^{β})	Equilibrated product
Iodine addition, %	5·2	39·5	44·1	61·5	39·9

By interpolation, the equilibrium mixture of acids contains 46% of Δ^{α}-acid, which agrees well with the amount isolated by means of partial esterification.

The Δ^{β}-acid (2·3 g.) was kept for 2 days with 50% sulphuric acid (10 c.c.). The homogeneous liquid was diluted and extracted with ether, and the extract washed with aqueous sodium bicarbonate and dried over sodium sulphate. Removal of the ether and distillation yielded 1·2 g. of *cyclo*hexane*spiro*butyrolactone, b. p. 130—133°/12 mm., m. p. 20°, alone or admixed with lactone prepared by oxidation of butenyl*cyclo*hexanol. The lactone (1·80 g.) was boiled for 6 hours with 50 c.c. of water, and the free hydroxy-acid titrated. The degree of hydrolysis was 1·96%.

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240. *Fused Carbon Rings. Part XIII. Synthesis of Derivatives of Decalin containing an Angular Methyl Group.*

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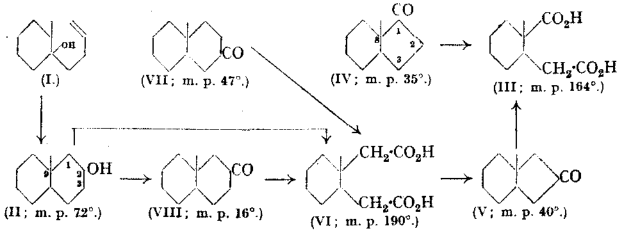
This paper is concerned with the preparation of pure hydronaphthalenes containing an angular methyl group, for use as control substances in investigations of dehydrogenation. Syntheses of 9-methyl-octalin and -decalin have already been described (J., 1936, 470, *et seq.*), and the position of the methyl group proved by degradation. Nevertheless these substances were not satisfactory as reference compounds, because, although they contained a considerable amount of material of the desired structure, the presence of isomeric impurity could not be excluded. For the same reason the *trans*-9-methyldecalin of Ruzicka, Koolhaas, and Wind (*Helv. Chim. Acta*, 1931, 14, 1154) did not appear to be a suitable reference

compound. We now report the preparation of homogeneous compounds of the desired type.

It was shown in the preceding paper that 1-Δ^{γ}-butenyl*cyclo*hexanol yielded *cis*-β-decalyl acetate, and thence *cis*-β-decalol, when treated with a mixture of acetic and sulphuric acids and acetic anhydride. The same treatment of 2-methyl-1-Δ^{γ}-butenyl*cyclo*hexanol (I) yielded a mixture of methyldecalols. The yield was considerably better than in the unsubstituted series, the methyl group, as usual, assisting ring-closure. From the mixture a 9-methyl-2-decalol (II), m. p. 72°, was separated. The structure was proved as follows: On oxidation with nitric acid it gave a dibasic acid, $C_{11}H_{18}O_4$, m. p. 190°, in good yield. Distillation of this with a little baryta gave a dicyclic ketone, $C_{10}H_{16}O$, m. p. 40°, which formed a semicarbazone, m. p. 220°. Oxidation of this ketone yielded 1-methyl*cyclo*hexane-1-carboxylic-2-acetic acid (III), m. p. 164°, identical with synthetic material (Linstead and Millidge, J., 1936, 478; Chuang, Tien, and Huang, *Ber.*, 1935, **68**, 864). The only ketones which could yield this acid on oxidation are 8-methyl-1-hydrindanone (IV) and 8-methyl-2-hydrindanone (V). One stereoisomeric form of the first of these has recently been synthesised and its structure is certain (Kon, Linstead, and Simons, this vol., p. 814). It also gives the 164°-acid on oxidation and therefore belongs to the same stereochemical series. It melts at 35° and its semicarbazone at 224°, but in spite of their similarity the two ketones are quite distinct (see experimental section). The new ketone, m. p. 40°, is therefore *8-methyl-2-hydrindanone* (V), and the parent acid 1-methyl*cyclo*hexane-1 : 2-diacetic acid (VI). It follows that the original methyldecalol has the hydroxyl group in the 2- or the 3-position,* which agrees with the fact that *cis*-β-decalol is formed by an analogous cyclisation.

On oxidation with chromic acid the methyldecalol, m. p. 72°, yielded a 9-methyldecalone, which, after regeneration from the semicarbazone, melted at 18°. du Feu, McQuillin, and Robinson (this vol., p. 53) have described the preparation of an isomeric ketone, m. p. 47°, which there was good reason to believe was a 9-methyldecalone, and if so was certainly 9-methyl-3-decalone (VII). Through the kindness of Professor Robinson and Mr. McQuillin we have examined this substance. It differs from our ketone, but on oxidation yields the same 1-methyl*cyclo*hexane-1 : 2-diacetic acid (VI), also obtained by oxidation of our alcohol. Hence: (i) du Feu, McQuillin, and Robinson's structure for their ketone and their interpretation of their elegant synthetic method are confirmed; (ii) both sets of compounds belong to the same stereochemical series, the configuration of which we discuss below; (iii) our ketone by exclusion is 9-methyl-2-decalone (VIII). The relationships are summarised in the scheme:



It has been said that the original cyclisation product was a mixture of isomeric alcohols. When the form of m. p. 72° was removed and the residue oxidised with chromic acid, the same ketone (VIII) was formed. Oxidation of the impure alcohol with nitric acid yielded the same acid (VI), but in this case it was possible to isolate a small quantity of an isomeride, m. p. 164°, a higher homologue of (III) (which has the same m. p.) and identical with the

* For convenience the carbon atom of octalins and decalins which carries the angular methyl group is referred to as C_9 throughout the introductions of this and the following paper.

acid obtained by Hibbit, Linstead, and Millidge (J., 1936, 478). It follows that the alcohol obtained by cyclisation is essentially a mixture of epimerides belonging to the same stereochemical series with respect to the locking of the rings (which we believe to be *cis*). The second C_{11} acid, m. p. 164°, is probably the stereoisomeride of (VI). It certainly belongs to the other stereoisomeric series (probably *trans*), for it has been degraded (*loc. cit.*) to the stereoisomeride of (III).

Reduction of pure 9-methyl-2-decalone (VIII) by the Clemmensen method yielded 9-methyldecalin, and dehydration of the solid alcohol (II) gave 9-methyloctalin. The oxygenated carbon atom is separated from the quaternary carbon atom (C_9) and there is therefore no possibility of a molecular rearrangement. On this account, and because the two hydrocarbons have been made from homogeneous solids, we have taken them as reference compounds for dehydrogenation experiments (see following paper). It is, of course, to be expected that the 9-methyloctalin will be a mixture of isomerides containing the double bond in different positions. On oxidation it yielded the diacetic acid (VI), which showed that it contained the Δ^2-form, and indicated that no molecular rearrangement had occurred during dehydration.

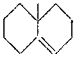
Configuration. The connection with the key-acid (III) shows that the compounds illustrated in the scheme all belong to the same stereochemical series. There is now strong (but not conclusive) evidence that they have the *cis*-configuration. This corrects an earlier suggestion (Linstead and Millidge, J., 1936, 480) that the 164°-acid (III) was the *trans*-acid, which was based on an unsatisfactory analogy. The new evidence comes first from the physical properties of pure 9-methyldecalin, 9-methyl-2-decalone, 8-*methylhydrindane* (made by reducing the ketone V) and 9-methyloctalin, the results from the last-named being less conclusive owing to the possibility of double-bond isomerism. All these have high densities and refractive indices and normal molecular refractivities; *e.g.*, the values for 9-methyldecalin and 9-methyl-2-decalone in round figures corrected to 20° are:

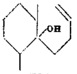
	$n_D^{20°}$.	$d_{4°}^{20°}$.	Exaltation in $[R_L]_D$.
9-Methyldecalin	1·481	0·892	−0·15
9-Methyl-2-decalone	1·492	0·989	+0·04

Related *trans*-ortho-dicyclic substances have exaltations of 0·3—0·4 of a unit. Furthermore the actual values for *n* and *d* for the 9-methyldecalin correspond well with those expected (cf. Ruzicka, Koolhaas, and Wind, *loc. cit.*; Hibbit and Linstead, J., 1936, 472). It is particularly interesting that the various *cis*-alkyldecalins derived from sesquiterpenes all have almost identical values for $d_{4°}^{20°}$ and $n_D^{20°}$ of about 0·89 and 1·48 respectively. The values for the ketone also fall into line well with those of *cis*-β-decalone, allowance being made for the usual fall in physical constants due to the methyl group. Secondly, the parent alcohol (II) is formed by a reaction which, in the case of the lower homologue, gives an undoubtedly *cis*-product (preceding paper).

In the light of these results, it is clear that the methyloctalins obtained by direct cyclisation of methylbutenyl*cyclo*hexanols (Parts VII and VIII) were mixtures of isomerides, as was foreshadowed in the earlier work. The final oxidation product in both cases was mainly the 1-methyl*cyclo*hexane-1-carboxylic-2-acetic acid, m. p. 174°, stereoisomeric with (III). Hence the liquid, unregenerated, methylhydrindanone from which it had been obtained was a mixture containing *trans*-8-methyl-2-hydrindanone. The physical properties, however, indicate the presence of *cis*-material, and the 164°-acid was isolated from one oxidation (Part VIII). The parent methyloctalin must therefore have contained some of the *trans*-9-methyl isomeride. It is possible that the high physical constants indicate the presence of the $\Delta^{4:10}$-isomeride (IX). The double bond would be labile under the conditions of cyclisation (see preceding paper) and it might well migrate to the $\Delta^{4:10}$-position. A reversible migration of this kind would account for the formation of *trans*-octalins from primarily formed *cis*-isomerides. The presence of (IX) would account for the formation of a 9-methyldecalin, essentially *cis*-, on reduction, for there is evidence that bridge-head double bonds are reduced catalytically in this sense. The possible presence of derivatives of 1-methyldecalin is discussed in the next paper in the light of the results of dehydrogen-

ation. The general conclusion is that, although the earlier methods of cyclisation give good yields of dicyclic material, at least partly of the angular methyl type, they are not suitable for the preparation of homogeneous compounds.


(IX.)


(X.)

(XI.)

As a preliminary exploration of the synthesis of substances more closely related to sesquiterpenes by cyclisation of butenyl compounds, we have examined the dehydration of 2 : 6-*dimethyl*-Δ^{γ}-*butenyl*cyclo*hexanol* (X). In this compound there seems to be no possibility of ring closure other than in the sense indicated (X $\longrightarrow$ XI), molecular rearrangement being most improbable. With a mixture of phosphoric acid and anhydride the alcohol (X) yielded 4 : 9-*dimethyloctalin* (XI, position of double bond uncertain), which was hydrogenated to 4 : 9-dimethyldecalin. The physical properties of this (b. p. 84°/10 mm., $d_{4^\circ}^{20^\circ}$ 0·881, $n_D^{20^\circ}$ 1·477, $\Sigma[R_L]_D$ + 0·01) were fairly close to those of the *cis*-4 : 9-dimethyldecalin (b. p. 85°/12 mm., $d_{4^\circ}^{20^\circ}$ 0·890, $n_D^{20^\circ}$ 1·481, $\Sigma[R_L]_D$ – 0·04) obtained by Ruzicka, Koolhaas, and Wind from eudesmol (*Helv. Chim. Acta*, 1931, **14**, 1175). The indications are that the synthetic material contains some *trans*-material, probably formed through an intermediate of type (IX). The synthesis of the exact saturated compound formed from the natural products will clearly be complicated by the presence of three asymmetric centres.

Treatment of the synthetic 4 : 9-dimethyldecalin with aluminium chloride (cf. Zelinski and Turova-Pollak, *Ber.*, 1929, **62**, 1658; 1932, **65**, 1299) led to a fall in the physical constants, corresponding to a change to the *trans*-configuration. The dehydrogenation of 4 : 9-dimethyl-octalin and -decalin is described in the following paper.

EXPERIMENTAL.

[The configurations assigned to the compounds below are provisional, see p. **1142**.]

The reagent used for cyclisation was a mixture of 10 parts of glacial acetic acid, 1 part of acetic anhydride, and 1 part of concentrated sulphuric acid (by vol.). 2-Methyl-1-Δ^{γ}-butenyl-*cyclo*hexanol (Hibbit, Linstead, and Millidge, *loc. cit.*) was cooled in ice, and 5 vols. of this reagent added slowly with stirring. The mixture became purple and turbid, a colourless layer (probably an intermediate hydrocarbon) separated slowly and then redissolved in the reagent, which finally became deep red brown. After 4 days at room temperature, the mixture was poured into water and extracted with ether, the extract washed with ice-cold alkali, and the ether removed. The residue of acetate was refluxed for 2 hours with an excess of 20% methyl-alcoholic potash, and the methyldecalol isolated by means of ether. Distillation yielded a low-boiling fraction containing a mixture of hydrocarbon and alcohol, followed by a main fraction, b. p. 127—131°/10 mm., which on refractionation gave the methyldecalol, b. p. 128—130°/10 mm., 141°/21 mm., in an average yield of 55%. This soon deposited a large amount of solid, which after repeated crystallisation from light petroleum, yielded cis-9-*methyl*-2-*decalol* (II), m. p. 72°, as clumps of needles, almost odourless and very soluble in organic media (Found : C, 78·0; H, 11·7. $C_{11}H_{20}O$ requires C, 78·5; H, 12·0%). 170 G. of the refractionated alcohol (A) gave 40 g. of this pure solid (B), 50 g. of impure solid (C), and a residual liquid (D) which had a camphoraceous odour.

The pure decalol (B) (900 mg.) in 10 c.c. of glacial acetic acid was oxidised with 500 mg. of chromium trioxide dissolved in the minimum quantity of water. After ½ hour at room temperature the excess of reagent was destroyed by warm ethyl alcohol, and the ketone isolated by distillation in steam and extraction with light petroleum. The residue from the removal of the solvent was converted into semicarbazone, which was crystallised from methanol to constant m. p. 760 Mg. were obtained, m. p. 211—212° (bath initially at 200°), together with 160 mg. melting a little lower. 7·6 G. of refractionated methyldecalol (A) were similarly oxidised and yielded 6·1 g. of distilled ketone, b. p. 132—134°/21 mm., which gave the same semicarbazone. 46 G. of the impure solid (C) similarly gave 35 g. of this *semicarbazone*, m. p. 210—212° (Found : C, 64·9; H, 9·6. $C_{12}H_{21}ON_3$ requires C, 64·5; H, 9·5%). Regeneration from the semicarbazone (35 g.) yielded 24·4 g. of pure cis-9-*methyl*-2-*decalone* (VIII), which was isolated

by distillation in steam, and had b. p. 122—123°/14 mm., m. p. 17—18°, $n_D^{18°}$ 1·4937, $d_4^{18°}$ 0·9938; $[R_L]_D$ 48·64 (calc., 48·61) (Found: C, 79·8; H, 10·9. $C_{11}H_{18}O$ requires C, 79·4; H, 10·95%). The ketone obtained by oxidation of the crude decalol had physical properties almost identical with the above ($[R_L]_D$ 48·65). Hence there was little *trans*-impurity.

700 Mg. of pure 9-methyl-2-decalol (B) were added slowly to 5 c.c. of concentrated nitric acid, the temperature being kept below 30°. After 2 hours 5 c.c. of water were added, the product cooled in ice, and the solid acid filtered off and crystallised twice from dilute acetic acid (charcoal). cis-1-*Methylcyclohexane*-1 : 2-*diacetic acid* (VI) (520 mg.) had m. p. 189—190° (Found: C, 61·9; H, 8·5. $C_{11}H_{18}O_4$ requires C, 61·7; H, 8·45%). Similar oxidation of 21·8 g. of liquid decalol (D) yielded a crude acid, which was separated by fractional crystallisation into the above acid (7·8 g.), m. p. 189—190° [Found: equiv. (dibasic), 107·1. Calc., 107·1], and 1 g. of an acid, m. p. 163—165°. The m. p. of the latter was not depressed by the acid of Hibbit, Linstead, and Millidge (*loc. cit.*), which was described as the *cis*-diacetic acid but now appears to be probably the *trans*-isomeride. The *cis*-acid, m. p. 189—190°, depressed the m. p. of the isomeric acid, m. p. 194°, isolated in small amount by Hibbit and Linstead (*loc. cit.*, p. 476). It appears probable that the latter acid is an oxidation product of 1-methyloctalin, *e.g.*, a 3-methyl*cyclo*hexane-1 : 2-diacetic acid.

800 Mg. of regenerated 9-methyl-2-decalone were added in drops to 10 c.c. of boiling concentrated nitric acid under reflux. After a few minutes 4 c.c. of water were added, the boiling continued for 30 minutes, and the product diluted and evaporated to dryness over potash in a vacuum desiccator. The residual solid after crystallisation from dilute acetic acid (charcoal) yielded *cis*-1-methyl*cyclo*hexane-1 : 2-diacetic acid (250 mg.), m. p. and mixed m. p. 189—190°. Repetition failed to improve this yield and it seems generally true that dicyclic ketones give worse yields than the corresponding alcohols on oxidation with nitric acid.

450 Mg. of the 10-methyl-2-decalone (9-methyl-3-decalone, VII) of du Feu, McQuillin, and Robinson (*loc. cit.*), on oxidation in the same way, yielded 160 mg. of *cis*-1-methyl*cyclo*hexane-1 : 2-diacetic acid (m. p. and mixed m. p. 189—190°) together with a lower-melting acid in an amount insufficient for identification.

7·3 G. of the diacetic acid, m. p. 189—190°, were ketonised with 5% of baryta at 280—330°. The ketone distilled over and partly solidified; it was extracted with light petroleum, the extract washed with alkali, and the cis-8-*methyl-2-hydrindanone* (V) isolated, finally by distillation. It had b. p. 105°/14 mm. and at once solidified to a camphor-like mass (3·6 g.), m. p. 39—40° (Found: C, 78·5; H, 10·5. $C_{10}H_{16}O$ requires C, 78·9; H, 10·6%). The *semicarbazone* melted at 220° (Found: C, 63·3; H, 8·6. $C_{11}H_{19}ON_3$ requires C, 63·1; H, 9·2%). The alkaline washings and residual barium salt from the cyclisation regenerated the original acid (m. p. and mixed m. p.). On oxidation with boiling nitric acid by the method described above for 9-methyl-2-decalone, 2 g. of 8-methyl-2-hydrindanone yielded 1·5 g. of a crude acid, m. p. about 150°. After crystallisation this melted at 163—164° and did not depress the m. p. of the *cis*-1-methyl*cyclo*hexane-1-carboxylic-2-acetic acid of Linstead and Millidge (*loc. cit.*) but depressed the m. p. of the stereoisomeric acid, m. p. 174° (*ibid.*) to 140° (Found: C, 59·7; H, 8·0. Calc. for $C_{10}H_{16}O_4$: C, 60·0; H, 8·1%). The differences between this *cis*-8-methyl-2-hydrindanone and the 8-methyl-1-hydrindanone (IV) (now seen to be *cis*-) of Kon, Linstead, and Simons (*loc. cit.*) are summarised below:

	8-Methyl-1-hydrindanone.	8-Methyl-2-hydrindanone.
Physical properties	Camphor-like mass, m. p. 35°.	Camphor-like mass, m. p. 40°.
Smell	Very like that of camphor.	Similar, but weaker and more mentholic.
Semicarbazone	Not formed in cold, but rapidly on warming. Transparent flattened needles from methanol, m. p. 224°.	Formed almost instantaneously in cold. Shining leaflets from methanol, m. p. 220°.

A mixture of the two ketones melted indefinitely at 30°, and a mixture of the semicarbazones at 195—200°. The comparative difficulty of forming the semicarbazone of the α-ketone is probably due to steric hindrance by the adjoining alkyl group.

The methyl*cyclo*hexanecarboxylicacetic acid (m. p. 164°) is obtained in a purer form by the oxidation of the α-ketone than by that of the β-ketone, presumably because the former can only be oxidised (primarily) in one direction, whereas two routes are open for the latter. The semicarbazone of *cis*-8-methyl-2-hydrindanone depressed the m. p. of the semicarbazone, m. p. 220°, of Hibbit and Linstead (*loc. cit.*), which is probably the *trans*-isomeride.

12 G. of 9-methyl-2-decalone, regenerated from the pure semicarbazone, were boiled under

reflux with 140 g. of amalgamated zinc, 120 c.c. of acetic acid, and 60 c.c. of concentrated hydrochloric acid, in a slow stream of hydrogen chloride. After 7 hours at a bath temperature of 130°, the product was distilled in steam, and the distillate extracted with purified light petroleum. The extract was shaken with successive quantities of concentrated sulphuric acid until there was no more discoloration of the acid, then with water and dilute alkali. It was dried over calcium chloride, the solvent removed through a column, and the residue heated with potassium at 170° for ½ hour. cis-9-*Methyldecalin* was isolated by distillation, b. p. 79°/11 mm., $n_D^{12·5°}$ 1·4844, $d_{4°}^{12·5°}$ 0·8994; $[R_L]_D$ 48·45 (calc., 48·60). Yield: 8·9 g., 81% (Found: C, 86·8; H, 13·2. $C_{11}H_{20}$ requires C, 86·75; H, 13·25%). In solid carbon dioxide–ether it solidified to a camphor-like mass melting at about − 22°. By a similar treatment, 8-methyl-2-hydrindanone (7 g.) yielded 4·1 g. of cis-8-*methylhydrindane*, b. p. 56°/10·5 mm., $n_D^{13·5°}$ 1·4699, $d_{4°}^{13·5°}$ 0·8754, $[R_L]_D$ 44·02 (calc., 43·98) (Found: C, 86·6; H, 13·0. $C_{10}H_{18}$ requires C, 86·9; H, 13·1%). In solid carbon dioxide–ether it solidified to a camphor-like mass, m. p. 10—14°. The liquid is easily supercooled to − 10°.

Pure *cis*-9-methyldecalol was refluxed with an equal weight of anhydrous oxalic acid at 160° for 3 hours, and the residue distilled. The crude hydrocarbon, isolated by means of ether, was heated with sodium at 190° for ½ hour and then distilled over fresh sodium. Yield of cis-9-*methyloctalin*: 3·8 g. from 6 g. of alcohol. B. p. 78—80°/12 mm., $n_D^{16°}$ 1·4956, $d_{4°}^{16°}$ 0·9098, $[R_L]_D$ 48·16 (calc., $C_{11}H_{18}$ $\vDash_1$ 48·13) (Found: C, 88·1; H, 12·2. $C_{11}H_{18}$ requires C, 87·9; H, 12·1%). A second preparation had almost identical physical properties. 32 G. of the pure decalol were heated at 190—195° for 3 hours with powdered anhydrous potassium bisulphate. Water was added, and the product distilled in steam. *cis*-9-Methyloctalin was isolated as before, b. p. 78—80°/12 mm., $n_D^{16·2°}$ 1·4916, $d_{4°}^{16·2°}$ 0·9074, $[R_L]_D$ 47·96. The difference in the refractive index of this and the foregoing product shows that they are not exactly identical with respect to the position of the double bond. The last runnings of the steam distillation deposited unchanged 9-methyl-2-decalol, m. p. 72°.

A suspension of 9-methyloctalin (2·1 g.), prepared by means of oxalic acid, in aqueous sodium carbonate was oxidised with 3% potassium permanganate solution and yielded 0·21 g. of 1-methyl*cyclo*hexane-1 : 2-diacetic acid, m. p. 189°. The hydrocarbon prepared by means of potassium bisulphate gave a better yield of the same acid (0·58 g. from 2·3 g.), which showed that it contained more of the Δ^2-form.

Derivatives of 4 : 9-*Dimethyldecalin*.—6-Methyl*cyclo*hexanone-2-carboxylic ester (Ruzicka, Koolhaas, and Wind, *Helv. Chim. Acta*, 1931, **14**, 1161) was methylated by means of methyl iodide and molecular sodium in petroleum (b. p. 60—80°). The methylated ester (80% yield, b. p. 108—112°/9 mm.) was hydrolysed with baryta in 86% yield to 2 : 6-dimethyl*cyclo*hexanone, b. p. 56°/9 mm. Condensation of 86 g. of this ketone with the Grignard compound from 90 g. of butenyl bromide in the usual way yielded 48 g. of 2 : 6-*dimethyl*-1-Δ^{γ}-*butenyl*cyclo*hexanol* (X), which boiled at 100—105°/10 mm. with a tendency to dehydration (Found: C, 79·3; H, 12·2. $C_{12}H_{22}O$ requires C, 79·0; H, 12·2%). 9 G. of the alcohol were treated with a mixture of phosphoric acid and phosphoric oxide in the manner used for the cyclisation of the lower homologue (Hibbit, Linstead, and Millidge, *loc. cit.*). Fractionation of the product over sodium yielded 5 g. of 1 : 10 (= 4 : 9)-*dimethyloctalin* (XI), b. p. 86—90°/10 mm., $n_D^{15°}$ 1·4924, $d_{4°}^{15°}$ 0·9020, $[R_L]_D$ 52·84 (calc., $C_{12}H_{20}$ $\vDash_1$ 52·75) (Found: C, 87·7; H, 12·7. $C_{12}H_{20}$ requires C, 87·7; H, 12·3%). This rapidly absorbed the theoretical quantity of hydrogen (for one double bond) in acetic acid solution over Adams's catalyst. The product, after removal of the solvent, was shaken with potassium permanganate until the latter was no longer decolorised and isolated by distillation over sodium. The 1 : 10 (4 : 9)-*dimethyldecalin* (mainly *cis*-) so obtained had b. p. 84—85°/10 mm., $n_D^{16°}$ 1·4787, $d_{4°}^{15°}$ 0·8847, $[R_L]_D$ 53·23 (calc., 53·22) (Found: C, 86·6; H, 13·15. $C_{12}H_{22}$ requires C, 86·65; H, 13·35%). A mixture of this hydrocarbon with an equal weight of aluminium chloride was left in a desiccator for 2 days, and the hydrocarbon recovered in the usual manner. After distillation over sodium, it had b. p. 76—78°/10 mm., $d_{4°}^{15°}$ 0·8544, $n_D^{15°}$ 1·4658, $[R_L]_D$ 53·83, corresponding with the conversion into the *trans*-form.

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241. *Dehydrogenation. Part I. The Catalytic Dehydrogenation of Hydronaphthalenes with and without an Angular Methyl Group.*

By R. P. Linstead, A. F. Millidge, S. L. S. Thomas, and A. L. Walpole.

Ruzicka has shown the fundamental importance of dehydrogenation as a method for the determination of the structure of natural products containing the hydronaphthalene and similar, more complex, polycyclic groups. Dehydrogenation over noble metals provides a useful auxiliary or alternative method to dehydrogenation by selenium or sulphur, but our knowledge of the behaviour of various types of hydronaphthalenes over such catalysts is incomplete, and to some extent conflicting (for a review, see *Ann. Reports*, 1936, **33**, 305). In the present paper we describe the first stage in a general investigation of this question. The method of attack has been to examine the behaviour of substances of known structure over catalysts in the liquid and the vapour phase with the following practical objects: (1) *To find the mildest conditions suitable for the conversion of* hydroaromatic compounds into their aromatic counterparts without molecular rearrangements, such as the migration of alkyl groups. (2) To find a reliable test for the presence of an angular methyl (or similar) group, and, if possible, a method capable of giving evidence as to its position.

1. *Substances not containing an Angular Methyl Group.—Tetralins.* When liquid tetralin was boiled (208°) with platinum or palladium, naphthalene was rapidly formed. When the hydrogen evolved was led into a measuring apparatus so that a closed system was formed, far less than the theoretical quantity was evolved, owing without doubt to the reversal of the reaction. When, however, the hydrogen was swept from the reaction vessel in a stream of carbon dioxide, the reaction went smoothly to completion. The hydrogen was freed from carbon dioxide and measured in the apparatus described in the experimental section. The yields of hydrogen and naphthalene were theoretical within the limits of accuracy of the method. The reaction was unimolecular, the plot of $\log (V_\infty - V_t)$ against t being a straight line, where V_t is the volume of gas evolved in time t, and V_∞ the total volume evolved. Actually, an exact correspondence with theory was not to be expected, because the temperature was held at the boiling point, which rose slightly as the reaction proceeded. The results show that the reaction is a direct dehydrogenation and that no *disproportionation of hydrogen, with formation of decalin and naphthalene, occurred under these conditions.** *Tetralin was also catalytically dehydrogenated* at even lower temperatures, but not sufficiently rapidly to be of much practical interest.

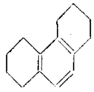
At the boiling point, the velocity of dehydrogenation depended on the catalyst. The most active catalysts were platinised charcoal, made by reducing hydrochloroplatinic acid with hydrogen at 135°, following Packendorff and Leder-Packendorff (*Ber.*, 1934, **67**, 1388), and a palladised charcoal made by reduction with formaldehyde in alkaline solution (Zelinski and Turowa-Pollak, *Ber.*, 1925, **58**, 1295). With these, reaction was nearly complete in four hours, with a half-change period of about an hour. This appears to be the best preparative method for obtaining naphthalenes from tetralins, and presumably also from dihydronaphthalenes. Ruzicka and co-workers have recently used palladised charcoal for the dehydrogenation of various derivatives of tetralin in synthetic work (*e.g.*, Ruzicka, Hösli, and Ehmann, *Helv. Chim. Acta*, 1936, **19**, 370).

To test whether polycyclic substances containing the tetralin system were dehydrogenated with similar ease we examined the *s.*-octahydrophenanthrene (I) and *s.*-octahydroanthracene (II) of Schroeter (*Ber.*, 1924, **57**, 1990 ff.). Both substances when boiled with palladium lost the theoretical quantity (4 mols.) of hydrogen in less than an hour, and quantitative yields of phenanthrene and anthracene respectively were isolated.

Decalins. Both *cis*- and *trans*-decalins, on the other hand, were only very slowly

* Zelinski (*Ber.*, 1923, **56**, 1724) states that tetralin yields decalin and naphthalene over platinum at 300°, but gives no experimental details. In view of the results described above, it seems most unlikely that any appreciable amount of decalin would be formed under these conditions. Zelinski's statement that the change is analogous to the disproportionation of *cyclo*hexene is not correct, for the double bond common to both rings in tetralin is part of an aromatic system and would be reduced much less readily than that of *cyclo*hexene.

dehydrogenated over the same catalysts in the liquid phase at the boiling point (*ca.* 190°), and to obtain a satisfactory yield of naphthalene it was necessary to work in the vapour

(I.) 

(II.)

phase at 300° (cf. Zelinski, *Ber.*, 1923, **56**, 1723). Under the latter conditions 1-*methyldecalin* readily yielded 1-methylnaphthalene and this appears to be the best practical method for dehydrogenating such saturated hydrocarbons.

Octalins. When *trans*-Δ^2-octalin or $\Delta^{9:10}$-octalin was boiled with palladium, the evolution of hydrogen was at first rapid, being comparable with that from tetralin, but after a few hours almost ceased. At this resting stage the yield of naphthalene was about a third of that calculated for complete dehydrogenation. The yield of hydrogen varied somewhat from experiment to experiment, but was roughly a sixth of that calculated on the same basis. The non-aromatic product was a decalin. These facts can be explained as follows: The octalin rapidly undergoes a disproportionation with the formation of decalin and tetralin in the molecular ratio of 2 : 1. The tetralin is then rapidly dehydrogenated in the normal manner:

$$\text{(i)}\ 3C_{10}H_{16} \longrightarrow 2C_{10}H_{18} + C_{10}H_{12} \qquad \text{(ii)}\ C_{10}H_{12} \longrightarrow C_{10}H_8 + 2H_2$$

The theoretical yields of hydrogen and naphthalene on this basis are $\frac{1}{6}$ and $\frac{1}{3}$ respectively of those required for the complete dehydrogenation: $3C_{10}H_{16} \longrightarrow 3C_{10}H_8 + 12H_2$.

In addition to these main reactions, it is reasonable to expect that there will be a little dehydrogenation of the decalin formed, and probably also some direct dehydrogenation of octalin to tetralin, and thence to naphthalene. In other words, some of the hydrogen liberated by the octalin molecules in their change to tetralin will escape free, without being employed in the reduction of other octalin molecules in the manner indicated by equation (i). The relative tendencies to disproportionation and direct dehydrogenation will be bound up with the ease of reduction of the double bond in the octalin—the more easily this is reduced, the greater the tendency to disproportionation. This was borne out experimentally, for the hydrogen evolution was greater from $\Delta^{9:10}$- than from Δ^2-octalin, which corresponds with the observation of Hückel, Danneel, Schwartz, and Gercke (*Annalen*, 1929, **474**, 121) that the double bond in the latter is hydrogenated much more readily than that in the former.

At lower temperatures the disproportionation was accompanied by very little dehydrogenation. When *trans*-Δ^2-octalin was heated with palladium at 140° or 170°, tetralin could be isolated in good yield [on the basis of equation (i)] in the form of its β-sulphonanilide. This disproportionation is similar to that observed in the *cyclo*hexene series by Knoevenagel, Zelinski, Boëseken, and others (for references, see *Ann. Reports*, 1936, **33**, 307); also Wieland (*Ber.*, 1912, **45**, 486) found that dihydronaphthalene yielded naphthalene and tetralin when heated over palladium.

1-*Methyloctalin* and *trans*-2-methyloctalin, prepared by dehydrating the corresponding tertiary alcohols, behaved similarly. The former gave the greater amount of hydrogen (28%), possibly because some $\Delta^{9:10}$-isomeride was present. The latter was essentially free from the $\Delta^{9:10}$-form, as it gave a white *nitrosochloride*. With palladium it yielded 2-methylnaphthalene, 2-*methyldecalin*, and 20% of hydrogen.

In the vapour phase over platinum and palladium at 300—350°, octalin and its 1- and 2-methyl derivatives gave the corresponding aromatic hydrocarbons in good yield. There was no evidence of the migration or elimination of the 1- or the 2-methyl group; *e.g.*, when 2-methyloctalin was passed over platinised asbestos at as high a temperature as 355°, 2-methylnaphthalene (m. p. 32°) solidified at the cool end of the tube.

No experiments have yet been carried out on di- and hexa-hydronaphthalenes, but on the basis of the above results it may be anticipated that at the boiling point in the liquid

phase these will undergo disproportionation, followed by complete and partial dehydrogenation respectively.

II. Substances containing an Angular Methyl Group.—9-Methyldecalin, made by reducing pure 9-methyl-2-decalone, and 9-methyloctalin, made by dehydrating solid 9-methyldecalol (Linstead, Millidge, and Walpole, this vol., p. 1145), will be considered first. When these substances were boiled with palladium in the liquid phase (at *ca.* 200°), no significant quantity of hydrogen was evolved. The 9-methyloctalin was recovered unchanged, in striking contrast to the behaviour of 2-methyloctalin. Both dehydrogenation and disproportionation are therefore stopped under these conditions, which are not sufficiently drastic to break the link holding the methyl group to the 9-carbon atom. It is interesting that 9-methyloctalin is recovered and not a mixture of the corresponding diene and decalin. If the disproportionation of an octalin (or a *cyclo*hexene) took place in two steps, there is no formal reason why the first of these, shown below, should not proceed even when an angular methyl group is present:

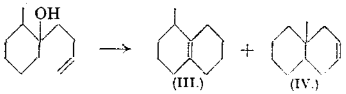
There is, however, no evidence that this occurs, perhaps because the reaction is reversible with an equilibrium on the left-hand side.

Very interesting results were obtained from experiments in the vapour phase at 300—330°. Dehydrogenation occurred, although rather more slowly than with compounds not containing the angular group. The fate of the methyl group depended upon the nature of the catalyst. With the platinum and palladium catalysts described above, the main product was naphthalene, the methyl group being eliminated, and some α-methylnaphthalene was formed by a secondary reaction. Over platinum prepared by Loew's method (*Ber.*, 1890, **23**, 289) the migration of the methyl group became the main reaction, α-methylnaphthalene being obtained, either alone or contaminated with only a trace of naphthalene. These surprising results have been repeated a number of times and there can be no doubt as to their authenticity. In parallel experiments, using different catalysts, we have obtained almost complete elimination and migration severally from one and the same sample of hydrocarbon. 9-Methyl-octalin and -decalin appeared to be essentially equivalent under the conditions of reaction. The formation of naphthalene was in itself a proof of the presence of the angular group, as direct experimental comparison showed that 1- and 2-methyl groups were not eliminated over the same catalyst under the same conditions.

Clemo and Dickenson (J., 1935, 735) report a failure to dehydrogenate a 9-methyldecalin over a platinum catalyst. The hydrocarbon was prepared by Clemmensen reduction of 2 : 4-diketo-9-methyldecalin (Ruzicka, Koolhaas, and Wind, *Helv. Chim. Acta*, 1931, **14**, 1154), a method which is not altogether reliable for the preparation of a pure compound owing to the danger of molecular rearrangement (cf. Dey and Linstead, J., 1935, 1063). Their result may, however, have been due to a lower catalyst activity. It is remarkable that Zelinski, Packendorff, and Chocklova (*Ber.*, 1935, **68**, 98; cf. Zelinski, *Ber.*, 1923, **56**, 1716) found that 1 : 1-dimethyl*cyclo*hexane was unaffected by a catalyst which we find capable of eliminating the angular methyl group from 9-methyldecalin. On the other hand, Ruzicka and Waldmann (*Helv. Chim. Acta*, 1933, **16**, 842; 1935, **18**, 611) have observed an almost quantitative elimination of angular methyl groups over palladium. The simple migration to the α-position now established is without precedent, although many examples are known of migration accompanying the elimination of a neighbouring substituent.

The dehydrogenation of the methyloctalins obtained by direct cyclisation of methylbutenyl*cyclo*hexanols may now be considered. The methyl group in the hydrocarbon obtained by dehydrating 1-methyl-2-butenyl*cyclo*hexanol (Hibbit and Linstead, J., 1936, 470) appears to be almost entirely in the 9-position, because the hydrocarbon gave off very little hydrogen when boiled with palladium. That obtained from the isomeric 2-methyl-1-butenyl*cyclo*hexanol (Hibbit, Linstead, and Millidge, J., 1936, 476), on the other hand, evolved hydrogen fairly readily. The aromatic product was α-methylnaphthalene, the non-aromatic was mainly a methyldecalin. Hence the methyloctalin made in this way

contains material with the methyl group in the 1- and not the angular position. This is formed by a " reversed " cyclisation away from the methyl group, a possibility suggested in the earlier paper. From the results of Linstead, Wang, Williams, and Errington (this vol., p. 1136) the hydrocarbon (III) with a $\Delta^{9:10}$-double bond is probably present. At



(III.) (IV.)

the same time the presence of 9-methyloctalin (such as IV) in the material is also certain from the results of oxidation and the fact that vapour-phase dehydrogenation over palladium yields a considerable amount of naphthalene.

When these octalins or the decalins prepared from them were dehydrogenated over Loew platinum at 330°, they yielded almost exclusively α-methylnaphthalene, whereas over palladium at this temperature a mixture of naphthalene and α-methylnaphthalene was obtained, consisting mainly of the former.* These results therefore fall into line with those from the homogeneous 9-methyl hydrocarbons.

4 : 9(1 : 10)-Dimethyloctalin, prepared from 2 : 6-dimethylbutenyl*cyclo*hexanol (preceding paper), gave very little hydrogen when boiled with palladium in a current of carbon dioxide, and even after 23 hours the octalin was recovered unchanged. Hence the compound is essentially of the angular methyl class. A little 1 : 5-dimethylnaphthalene was, however, obtained from the product, but in view of what follows this may well have been formed by migration during dehydrogenation (and not by dehydrogenation from already-formed 1 : 5-material). In the vapour phase at 330° over palladium 4 : 9-dimethyl-octalin and -decalin both yielded mainly α-methylnaphthalene, and 1 : 5-dimethylnaphthalene as by-product. Over Loew platinum at the same temperature no α-methylnaphthalene could be isolated, the main product being 1 : 5-dimethylnaphthalene, contaminated with an isomeride which has not yet been identified. Hence the main reactions over palladium and platinum at this temperature are elimination and migration of the methyl group respectively, as with the lower homologues.

For comparison with the unknown dimethylnaphthalene, 1 : 2-, 1 : 4-, and 1 : 8-dimethylnaphthalenes were synthesised, the last by a new and unequivocal method. None of these was identical with the dehydrogenation by-product, and it is possible that this is an inseparable mixture of isomerides. The identity of the 1 : 5-dimethylnaphthalene obtained by dehydrogenation was, however, established by comparison with synthetic material. The properties of these substances and of their derivatives are summarised in Table I.

Table I.

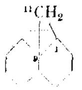
Substance.			Free hydro-carbon.	Picrate.	Styphnate.
x : x-Dimethylnaphthalene,		dehydrogenation	Liquid	Orange-red, m. p. 134°	Yellow, m. p. 145°
1 : 2-	,,	synthetic	,,	Orange, 131°	Chrome-yellow, 141°
1 : 4-	,,	synthetic	,,	Orange-red, 142°	Orange, 125°
1 : 8-	,,	synthetic	M. p. 63°*	Orange-yellow, 148°*	Orange-yellow, 160°
1 : 5-	,,	dehydrogenation	77°	Yellow, 137°	—
1 : 5-	,,	synthetic	79°	Yellow, 137°	—

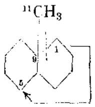
* 1 : 8-Dimethylnaphthalene is described by Veselý and Štursa (*Coll. Czech. Chem. Comm.*, 1931, **3**, 430) as an oil (picrate, m. p. 143°).

Any proposed mechanism for the migration of the methyl group must allow for the fact that the α-methylnaphthalene obtained from 9-methyl-decalin and -octalin contained no

* In 1933, Dr. D. C. Hibbit obtained naphthalene by dehydrogenating 9-methyloctalin (prepared from 1-methyl-2-butenyl*cyclo*hexanol) over Loew platinum (thus showing the presence of the angular methyl group), but we have not since had a Loew catalyst capable of eliminating the angular group in this way. This illustrates the dependence of catalyst activity on minor variations in the method of preparation.

detectable amount of the β-isomeride, and also that migration was independent of the presence of a double bond. Two essentially different explanations may be considered: (*a*) The bond connecting the methyl group to C_9 is broken, but the hydrocarbon fragment remains adsorbed on the catalyst and is able to recombine with the hydronaphthalene residue at some stage during its dehydrogenation. There is evidence that catalysts can adsorb hydrocarbon fragments, *e.g.*, in the work of Taylor and co-workers (*J. Amer. Chem. Soc.*, 1935, **57**, 592). Alternatively, (*b*) the methyl group does not part from C_9 until it combines with C_1. In other words the first stage * is dehydrogenation with the formation of a three-membered ring (V). This would be extremely unstable, for both the 1 : 11- and the 9 : 11-bond would tend to break with addition of hydrogen. The former would merely

(V.) 

 (VI.)

reverse the reaction, but the latter would subsequently enable dehydrogenation to go to completion and would therefore be the effective process. There is no analogy for the formation of such a *cyclo*propane compound, although Haworth, Mavin, and Sheldrick have suggested the formation of an intermediate 5-membered ring to explain the migration of methyl from C_4 to C_1 during the selenium dehydrogenation of certain hydrophenanthrenes (J., 1934, 454). The reductive fission of the *cyclo*propane ring over dehydrogenating catalysts is, however, well established (Zelinski and Levina, *Annalen*, 1929, **476**, 60). Models indicate that the strain in the 3-membered ring of (V) is not substantially greater than that in an isolated *cyclo*propane ring. An alternative explanation which at first appeared attractive is illustrated by formula (VI), the suggestion being that the 1 : 9-bond breaks and the 4-carbon side-chain then cyclises on to C_5, subsequent dehydrogenation leaving the methyl group in the α-position. This explanation, however, fails to account for the formation of 1 : 5-dimethylnaphthalene from 4 : 9-dimethyloctalin.

We hope to be able to decide between these possibilities by further study of migration reactions. At present, the hypothesis of an intermediate ring seems more acceptable, as otherwise it is difficult to explain the preference for migration to the α-position.

The *elimination* of the methyl group involves the fission, probably the reductive fission, of a carbon-to-carbon bond. Of the four bonds of the quaternary carbon atom, C_9, there is no *prima facie* reason why that holding the methyl group should alone be broken. Hence it might be anticipated that, under conditions leading to elimination of an alkyl group, the total yield of naphthalene derivatives might be lowered by ring fission. On the whole this appears to be true in our experiments, but it is not universally correct, for Ruzicka and Waldmann obtained excellent yields of retene from abietic acid and fichtelite (*loc. cit.*).

The investigation is being extended to other synthetic compounds and to natural products, and a further examination of catalysts is being made.

Experimental.

I. *Materials.*—Tetralin was purified by fractional distillation, sulphonation, and hydrolysis of the sulphonate, following Schroeter (*Annalen*, 1922, **426**, 111).

trans-Decalin was prepared by fractionation of commercial decalin. *cis*-Decalin was obtained as a by-product in the preparation of *cis*-β-decalol from *ac*-β-tetralol (we are indebted to Mr. D. A. H. Parsons for this material). *trans*-Δ^2-Octalin was prepared by dehydrating *trans*-β-decalol with potassium hydrogen sulphate and refluxing the product over potassium. $\Delta^{9:10}$-Octalin (principally this isomeride) was prepared by dehydrating *trans*-β-decalol with phosphoric acid (Linstead, Wang, Williams, and Errington, *loc. cit.*) and as follows: A mixture of 100 g. of *trans*-β-decalol and 240 g. of crystalline oxalic acid was refluxed for 9 hours at about 160°, and the product distilled in steam. The hydrocarbon was dried and fractionally distilled, finally over

* *I.e.*, the first stage in the migration; the loss of hydrogen from other parts of the molecule may occur earlier.

sodium. It was a mixture of octalins, the main fraction (31 g.) boiling at 84—86°/22 mm. and yielding the blue nitrosochloride of the $\Delta^{9:10}$-isomeride, m. p. 91—92° (cf. Hückel, Danneel, Schwartz, and Gercke, *loc. cit.*).

1-*Methyl-octalin and -decalin.* *ar*-α-Tetralol was reduced in acetic acid solution over Adams's catalyst. The resulting α-decalol was oxidised to α-decalone, following Hückel and Brinkmann (*Annalen*, **1925**, **441**, 28). The ketone was only partly solid in ice and hence was the *cis*-isomeride, not quite pure. The ketone (9·5 g.) was converted into 1-*methyl*-1-*decalol* by treatment with methylmagnesium iodide. The carbinol (9 g., b. p. 112—113°/10 mm.) appeared from the analysis to be slightly dehydrated (Found: C, 79·5; H, 12·2. $C_{11}H_{20}O$ requires C, 78·5; H, 12·0%). It was heated for 2 hours at 130—140° with an equal weight of anhydrous oxalic acid, and the 1-*methyloctalin* isolated by means of ether and distilled over sodium. Yield, almost theoretical; b. p. 81—83°/10 mm. (Found: C, 88·05; H, 12·1. $C_{11}H_{18}$ requires C, 87·9; H, 12·1%). It rapidly absorbed the theoretical quantity of hydrogen over Adams's catalyst in acetic acid solution. The 1-*methyldecalin* (mainly *cis*-), after purification by treatment with potassium permanganate and distillation over sodium, boiled at 80—81°/12 mm. (Found: C, 86·75; H, 13·2. $C_{11}H_{20}$ requires C, 86·75; H, 13·25%).

trans-2-Methyloctalin was prepared by dehydrating *trans*-2-methyl-2-decalol (Ruzicka, Koolhaas, and Wind, *Helv. Chim. Acta*, 1931, **14**, 1163) with oxalic acid. It had b. p. 80°/11 mm., and with amyl nitrite and concentrated hydrochloric acid gave a white *nitrosochloride*, which formed plates from ether, m. p. 138°, contaminated with only a trace of greenish-blue material (Found: Cl, 16·7. $C_{11}H_{18}ONCl$ requires Cl, 16·5%).

The 9-methyl- and 4 : 9-dimethyl-octalins and -decalins were prepared as described in the preceding papers and in J., **1936**, 470, 476. Octahydrophenanthrene, m. p. 17°, and octahydroanthracene, m. p. 73—74°, were prepared from tetralin and purified essentially by Schroeter's methods (*loc. cit.*, 1924).

The physical properties of these hydrocarbons are tabulated below to facilitate comparison with the corresponding values for the dehydrogenation products.

TABLE II.

Hydrocarbon.	B. p./mm.	$n_D^{t°}$.	$d_{4°}^{t°}$.	*t*.	Exaltation of $[R]_D$.
trans-Δ^2-Octalin	70°/12	1·4859	0·8956	17·0°	+0·07 }
$\Delta^{9:10}$-Octalin (oxalic acid)	85/22	1·4992	0·9256	16·5	−0·36 }
1-Methyloctalin (mainly *cis*-)	82/10	1·5006	0·9155	12·0	+0·17 }
trans-2-Methyloctalin	80/11	1·4865	0·8893	17·3	+0·47 }
cis-9-Methyloctalin (from solid alcohol)	79/12	1·4916	0·9074	16·2	−0·17 }
1-Methyldecalin (mainly *cis*-)	81/12	1·4813	0·8905	12·5	−0·03 }
cis-9-Methyldecalin (from ketone)	79/11	1·4844	0·8994	12·5	−0·15 }
4 : 9-Dimethyloctalin	88/10	1·4924	0·9020	15·0	+0·09
4 : 9-Dimethyldecalin	85/10	1·4787	0·8847	16·0	+0·01

II. *Catalysts.*—The following were the most useful catalysts: *Platinum* (1). Platinised asbestos containing 32% of metal, made by Zelinski and Borisoff's modification (*Ber.*, **1924**, **57**, 150) of Loew's method (*loc. cit.*), washed free from alkali with water, and dried at 100°.

Platinum (2). Aqueous hydrochloroplatinic acid from 2·25 g. of platinum was absorbed on 7 g. of charcoal (supernorit, first warmed with 5% nitric acid, washed with hot water, and dried at 120°). The reagent (24% platinum) was dried at 100° and reduced with purified hydrogen, first at 100°, then for 7 hours at 135°, and finally for 2 hours at about 300° (compare Packendorff and Leder-Packendorff, *loc. cit.*).

Palladium (1). Palladised charcoal (supernorit) containing 30% of metal, made following Zelinski and Turowa-Pollak (*loc. cit.*), washed with hot water until the washings were no longer alkaline, and dried at 150°.

Palladium (2). Made similarly in 25% strength, but washed with hot water, dilute acetic acid, and then again with water. It was slightly more active than palladium (1).

These catalysts were cooled and stored in a desiccator. For vapour-phase experiments the catalysts mounted on charcoal were mixed with an equal weight of purified asbestos, to prevent movement in the tube. The metal was recovered from spent catalysts by exhaustive extraction with aqua regia, the extracts evaporated to dryness, and the platinum precipitated from a solution in hydrochloric acid by means of formaldehyde and alkali. The metal was then redissolved and used afresh for the preparation of catalyst. The activity of the catalyst so obtained was tested quantitatively for the dehydrogenation of tetralin and found to be equal to that from fresh metal. Palladised silica gel (formaldehyde reduction) and palladium made by reducing the

diamminochloride with hydrogen (Keiser and Breed, *Amer. Chem. J.*, **1894**, **16**, **20**) were also tested against tetralin and found to be considerably less active than palladium (1).

III. *Liquid Phase Dehydrogenations.*—(i) *No Measurement of hydrogen.* In the first series of experiments the hydrocarbon was boiled with the catalyst in a flask fitted with a vertical condenser open to the air. After a suitable time, the product was separated from the catalyst by distillation or by extraction with ether, filtration and removal of the solvent under a column. The aromatic hydrocarbons were isolated either as such or as picrates. The yields given below refer to hydrocarbon dried on a porous tile or are calculated from the weight of recrystallised picrate.

Tetralin. After 5 c.c. (4·85 g.) of tetralin had been boiled for 22 hours with 0·5 g. of palladium (1), the catalyst was quite dry and the naphthalene had sublimed up the tube. Yield, 97%; m. p. and mixed m. p. 81°.

In 1 and 6 hours under the same conditions, the yields were 37% and 87% respectively. With platinum (1) under similar conditions for 21 hours, the yield of naphthalene was 78%. When tetralin was heated with palladium (1) for 4 weeks at about 90°, or boiled with the same catalyst under a pressure of about 20 mm., in a stream of carbon dioxide for 18 hours, very small yields of naphthalene were obtained.

trans-*Decalin.* 10 C.c. (8·79 g.) in 21 hours' boiling with 1 g. of platinum (1) and palladium (1) gave 2·15 g. and 1·15 g. respectively of naphthalene picrate (12 and 6·5% yields).

$\Delta^{9:10}$-Octalin (10 c.c., 9·2 g.), made from *trans*-β-decalol and phosphoric acid, after 23 hours' boiling with 1 g. of palladium (1) yielded in two experiments 33·5 and 33% of naphthalene, isolated as picrate. Octalin, made by oxalic acid dehydration, similarly gave a 30, 36% yield. To estimate approximately the loss involved in the isolation of naphthalene picrate, naphthalene contaminated by twice its weight of decalin was converted into picrate. The yield was 90%. Hence the true yield of naphthalene in these dehydrogenations is about 37%, *i.e.*, rather more than the 33% calculated from equations (i) and (ii) (p. 1147).

Disproportionation of octalins. (a) 5 C.c. of octalin (oxalic acid method) were boiled for 6 hours with 0·5 g. of palladium (1). The product was cooled to − 16°, and the naphthalene filtered off by means of a filter-stick and dried (0·31 g.). The filtrate yielded 0·61 g. of naphthalene picrate (m. p. 151°). The residue was taken up in ether, and the excess of picric acid removed with ammonia. After removal of the solvent, the residual hydrocarbon was warmed for 30 minutes with 100% sulphuric acid to sulphonate the tetralin present. The product was diluted, extracted with ether, washed with aqueous ammonia and water, dried, and distilled. It gave 2·2 g. of decalin, b. p. 65—67°/12 mm., and 0·39 g. of a fraction, b. p. 81—82°/12 mm., probably a mixture of tetralin and unchanged octalin. The decalin had $n_D^{16.8°}$ 1·4806 and $d_{4°}^{16.8°}$ 0·8861 (Found: C, 87·2; H, 12·6. Calc.: C, 87·0; H, 13·0%). It was therefore a mixture of the *cis*- and the *trans*-form. The yields of naphthalene and decalin were 12% and 47% respectively. Allowance being made for the loss involved in the isolation of the decalin, which is appreciably volatile in ether, these yields indicate that disproportionation is complete but dehydrogenation incomplete under these experimental conditions.

(b) 5 G. of Δ^2-octalin (potassium hydrogen sulphate) and 0·4 g. of palladium (2) were heated for 4 hours at 170°. After separation of picrate, corresponding to 0·3 g. of naphthalene, and removal of the excess of picric acid, the residual oil (4·3 g.) was sulphonated for 3 hours with 1·7 c.c. of concentrated sulphuric acid on the steam-bath. Saturated brine was then added (10 c.c.), which precipitated 2·0 g. of sodium tetralin-β-sulphonate. This was dried and heated with phosphorus pentachloride (1·0 g.) for 3 hours, the melt poured on ice, and the acid chloride extracted with ether. The ethereal solution was evaporated three times with a slight excess of aniline, and the β-sulphonanilide crystallised from alcohol. Yield, 0·75 g.; m. p. 152° (cf. Schroeter, *loc. cit.*, *1922*). In a control experiment pure tetralin (2·2 g.), mixed with an equal weight of decalin, was converted similarly into 3·2 g. of sodium salt and 1·3 g. of the same sulphonanilide. On this basis the corrected yield of tetralin formed by disproportionation of the octalin was about 1·3 g., which, together with the naphthalene formed by dehydrogenation, corresponds approximately to the 33% yield required by theory.

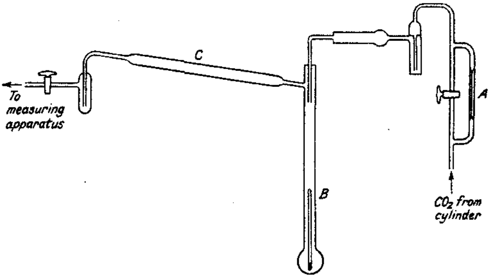
5·3 G. of *trans*-Δ^2-octalin were heated for 10 hours with 0·5 g. of palladium (2) in a boiling xylene bath. The product yielded (i) 1·3 g. of recrystallised naphthalene picrate, corresponding to 0·47 g. of naphthalene; (ii) 2 g. of sodium tetralin-β-sulphonate, and thence the sulphonanilide; (iii) a residual oil (2·5 g.), which on fractionation gave a little unchanged octalin and mainly *trans*-decalin, the latter having physical constants almost identical with those given by Hückel.

Methyloctalins. 5·2 G. of 1-methyloctalin were boiled with 0·5 g. of palladium (1) for 23

hours. Distillation yielded 3·5 g. of product with $n_D^{16·5°}$ 1·5302, $d_{4°}^{16·6°}$ 0·9366 and hence containing much aromatic material. This gave 3·8 g. of α-methylnaphthalene picrate, m. p. 141° (29%).

15·2 G. of *trans*-2-methyloctalin were boiled for 6 hours with 1·5 g. of palladium (1). Distillation under 12 mm. yielded 14·6 g. of product with $n_D^{14·5°}$ 1·501, $d_{4°}^{14·6°}$ 0·8991, which gave 7·2 g. of β-methylnaphthalene picrate, m. p. 117° (19%). The residue was purified by successive treatment with ammonia, sulphuric acid and water, dried, refluxed over potassium, and distilled at 70—76°/12 mm. (7·8 g., 51%). On refractionation *trans*-2-methyldecalin was obtained, b. p. 74—76°/12 mm., $n_D^{20°}$ 1·4700, $d_{4°}^{20°}$ 0·8640, $[R_L]_D$ 49·05, exaltation + 0·45. These physical constants are close to those observed by Ruzicka, Koolhaas, and Wind (*loc. cit.*) (Found: C, 86·7; H, 13·1. Calc. for $C_{11}H_{20}$: C, 86·7; H, 13·3%). Under Rosenmund and Kuhnhenn's conditions the hydrocarbon only reacted with 0·3% of the theoretical quantity of bromine required for one double bond, which confirmed the fact that it was saturated.

9-Methyloctalin * (3·6 g.) was boiled with 0·4 g. of palladium (1) for 23 hours. The product, after distillation from the catalyst, yielded no picrate. After removal of the picric acid and distillation, the methyloctalin (1·6 g.) was recovered unchanged, b. p. 79—80°/10 mm., $n_D^{16°}$ 1·4954, $d_{4°}^{16°}$ 0·9088, values almost identical with those of the starting material (see Table II) (Found: C, 87·8; H, 12·3. Calc. for $C_{11}H_{18}$: C, 87·9; H, 12·1%).



1 : 10(4 : 9)-Dimethyloctalin (5·2 g.) was boiled with 0·5 g. of palladium (1) for 23 hours, and the product distilled (4·1 g.). On cooling in ice-salt, 1 : 5-dimethylnaphthalene separated and was collected by means of a filter-stick and identified by m. p. and mixed m. p. (0·4 g.). The filtrate was freed from a trace of residual aromatic hydrocarbon with picric acid and after distillation had b. p. 90°/10 mm., $n_D^{18°}$ 1·4905, $d_{4°}^{18°}$ 0·8988 (Found: C, 87·5; H, 12·3. Calc. for $C_{12}H_{20}$: C, 87·7; H, 12·3%). These figures show that the recovered octalin was practically free from decalin.

(ii) *Measurement of hydrogen.* The apparatus in its final form is shown diagrammatically in the figure. Carbon dioxide from a cylinder was led at a steady rate, controlled by the capillary by-pass, *A*, through a water bubbler and potassium carbonate drying-tube to the vertical reaction vessel, *B*. This contained known weights of the hydrocarbon and catalyst and a thermometer immersed in the liquid. It was heated electrically. The gas then passed through a straight inclined tube of sofnolite, *C*, and a micro-bubbler containing aqueous potassium hydroxide, to a graduated receiving apparatus, also containing potash. The main features aimed at were a small dead space and an absence of pockets in which hydrogen could collect, and escape being swept out by the carbon dioxide. The apparatus was assembled, and the air displaced as far as possible by carbon dioxide. The reaction vessel was then heated so as to keep the hydrocarbon boiling vigorously, a steady stream of carbon dioxide was maintained, and the evolution of gas measured at suitable intervals. When no more gas passed through the micro-bubbler, the apparatus was swept out with carbon dioxide and the final volume of hydrogen measured. Two small corrections were necessary: (*a*) for the permanent gas present as im-

* The 9-methyloctalin used in the experiments described in this and the following (vapour-phase) section was the pure material prepared by dehydration of solid 9-methyl-2-decalol; and the 9-methyldecalin, by reduction of regenerated 9-methyl-2-decalone. Dehydrogenation experiments with methyloctalins of less certain purity, prepared by phosphoric acid dehydrations, are described in section V.

purity in the carbon dioxide, which was determined in blank experiments. (*b*) At the beginning of a run the sofnolite tube (and micro-bubbler) contained air, at the end hydrogen, except for the part containing spent sofnolite, which contained carbon dioxide. This "exhausted" part of the tube was greater at the end of an experiment and the volume of hydrogen was therefore slightly too large, and a small correction had to be applied. The accuracy of the method is estimated at about 5%. As an example of the results obtained, an experiment with tetralin is given below in detail; other experiments are summarised.

TABLE III.

0·91 G. of tetralin, 0·1 g. of Pd(1) at b. p. Gas measured at 768 mm. and 14°. Theo. evolution of hydrogen, 326 c.c.

Time (mins.) ...	10	20	30	40	61	80	103	120	165	189	210	240	270
C.c. of gas	8	20	60	89	131	162	195	217	255	273	284	297	307
,, ,, (corr.)	13	24	64	92	132	161	192	213	247	263	272	283	291
% Theo.	4	7	20	28	40·5	49	59	65	76	81	83	87	89
k (unimolecular) × 10^3	—	—	7·3	8·3	8·5	8·5	8·6	8·8	8·6	8·7	8·6	8·4	8·3

After 360 and 390 mins. the corrected volume of hydrogen was 300 c.c. (92%).
Mean k = $8·5 \times 10^{-3}$ (t in mins.).

Other catalysts gave the following evolutions of hydrogen from tetralin, expressed as % of the theoretical quantity for complete dehydrogenation.

TABLE IV.

Time (mins.)	20	40	60	80	100	120	210	300	Final
Reaction with Pd(1)	21	36	—	—	64	69	87	94	95
,, ,, Pd(2) *	26	—	47	59	—	72	91	—	91
,, ,, Pd(2)	21	40	—	68	73	—	—	—	96
,, ,, Pt(2)	25	43	59	66	81	83	89	90	90

* Catalyst made from recovered palladium.

The corresponding approximate velocity constants are: palladium (1) 10·6; palladium (2) 10·7, 13·0; platinum (2) 14·4 (all × 10^{-3}, t in mins.).

TABLE V.

% Evolution of hydrogen from octahydroanthracene and octahydrophenanthrene at b. p. (0·85 g. of hydrocarbon + 0·19 g. of catalyst).

Time (mins.)	3	8	10	15	21	32	37·5	Final
Octahydroanthracene + Pd(1)............	7	36	44	63	79	89	95	97·5
,, + Pt(2)............	10	34	44	63	79	93	97	103
Octahydrophenanthrene + Pd(1)	8	31	—	63	84	99	—	103

The anthracene from the dehydrogenation of octahydroanthracene had sublimed up the reaction vessel. It was extracted with benzene and crystallised from acetic acid; m. p. and mixed m. p. 211°; yield, theoretical. The phenanthrene from the octahydrophenanthrene was extracted with ether and identified by its m. p. (99°) and picrate, m. p. 143°; yield, theoretical. Dehydrogenation of octahydroanthracene by palladium (1) at a bath temperature of 240—250° gave about 50% evolution of hydrogen in 10 hours.

In the same apparatus *cis*-decalin at the b. p. over palladium (2) gave 4% of hydrogen in 100 minutes, and 8% in 28 hours. The evolution of hydrogen from *trans*-decalin was even slower.

TABLE VI.

% Evolution (corrected) of hydrogen from octalins and methyloctalins at the b. p. over 10% of palladium (1). For convenience in tabulation many of these figures were obtained by interpolation between the experimental values. The gas evolution is expressed as the percentage of that obtainable in complete dehydrogenation to naphthalenes.

Time (mins.)	20	40	60	80	100	200	300	400
$\Delta^{9:10}$-Octalin	7	11	14	16	18	22	24	24
Δ^{2}-Octalin	5	6	7	8	9	12	13	13
1-Methyloctalin	14	20	25	27	27	28	27	27
2- ,, ...	10	14	16	18	19	20	19	19

The dehydrogenation of the methyloctalins was more rapid on account of the higher b. p. The product from 1-methyloctalin was extracted with ether and yielded α-methylnaphthalene picrate, m. p. 141° (0·68 g., 26%).

cis-9-Methyloctalin yielded 3% of hydrogen after 19 hours at the b. p. over the same catalyst, and the residue gave a trace (*ca.* 1%) of a picrate (m. p. 147°) which appeared to be a mixture of naphthalene and α-methylnaphthalene derivatives. 4 : 9-Dimethyloctalin yielded 5% and 6% of hydrogen in two experiments for 5 hours under the same conditions. A little 1 : 5-dimethylnaphthalene picrate was isolated from the product. Hence a small amount of dehydrogenation of angular methyl compounds appears to occur under these conditions.

IV. *Vapour Phase Dehydrogenations.*—The reaction tube of Pyrex glass, inclined at about 15° to the horizontal, was connected by ground joints to an apparatus for dropping in the substance to be dehydrogenated and for admission of hydrogen, and at the lower end to a receiver and measuring apparatus. The tube, packed with catalyst, was swept out by a current of hydrogen, purified by means of solutions of acid permanganate, copper sulphate, silver nitrate, sodium plumbite, and dried with calcium chloride. The tube was then heated electrically to the desired temperature in a slow current of hydrogen, the gas stream was stopped, and the apparatus tested for leaks. A weighed quantity of hydrocarbon (generally about 1 g.) was then added at the rate of about 0·3 g. per hour, a slight suction (*ca.* 2 feet of water) being maintained in the measuring apparatus. The volume of gas evolved was noted, and the catalyst tube swept out with hydrogen until no more dehydrogenated product was collected. In some experiments the material was recirculated over the catalyst. This is specially referred to in the account of the individual experiments; where no reference is made, the material was only passed over the catalyst once. The product was cooled in a freezing mixture, any solid hydrocarbon separated, and the remaining aromatic material isolated as picrate. The % yields of gas are calculated on the basis of complete dehydrogenation.

cis-Decalin gave a 95% yield of naphthalene over platinum (1) at 330° (m. p. 81°; picrate, m. p. 149°). *trans*-Δ^2-Octalin over palladium (1) at 300° gave 82% of gas and a product containing 73% of solid naphthalene (m. p. 80—81°) and a little decalin or unchanged octalin.

1-Methyloctalin over platinum (1) at 330° gave 80% of hydrogen. The product yielded α-methylnaphthalene picrate, m. p. 140°. 1-Methyldecalin behaved in an almost identical manner. 2-Methyloctalin over platinum (1) at 300° gave only 50% of hydrogen in two passages, but at 355° gave 70% in one passage. The product from each experiment solidified in ice and yielded β-methylnaphthalene picrate, m. p. 115°. Over palladium (1) at 300°, 2-methyloctalin yielded 80% of hydrogen in one passage, and the same product.

9-*Methyl derivatives* (see also Section V). 9-Methyldecalin (1·07 g.) over platinum (2) at 330° yielded 95% of gas and a product which was separated into 0·4 g. of solid naphthalene (m. p. 80°) and a trace (*ca.* 0·03 g.) of α-methylnaphthalene, identified as picrate, m. p. 141—142°. 9-Methyldecalin (1·2 g.) over palladium (1) at 320° yielded 70% of gas and 0·56 g. of product, mainly solid naphthalene; the liquid yielded 0·3 g. of a picrate, m. p. 143—145°, a mixture of naphthalene and α-methylnaphthalene derivatives. 9-Methyldecalin (1·2 g.) in two passages over platinum (1) at 300° yielded 70% of gas and 1·03 g. of an oil depositing no solid in ice and salt. After treatment with picric acid and fractional crystallisation it yielded 0·9 g. of α-methylnaphthalene picrate, m. p. 141—142°, and no detectable amount of naphthalene picrate. In one passage over the same catalyst at 340° there were obtained 50% of gas, a trace of naphthalene by freezing the product, and the main product was again α-methylnaphthalene (picrate, m. p. 140°. Found : C, 54·9; H, 3·6. Calc. for $C_{17}H_{13}O_7N_3$: C, 55·0; H, 3·5. Calc. for $C_{16}H_{11}O_7N_3$: C, 53·8; H, 3·1%).

9-Methyloctalin (potassium hydrogen sulphate product) over palladium (1) at 330° gave a product which partly solidified in ice; it was separated as before into naphthalene (m. p. 80°; picrate, m. p. 151°) and α-methylnaphthalene (picrate, m. p. 141·5—142·5°. Found : C, 55·0; H, 3·4%).

After two passages over platinum (1) at 330°, the product from 9-methyloctalin failed to solidify in ice, and the only aromatic hydrocarbon present was α-methylnaphthalene (picrate, m. p. 138—140°. Found : C, 54·8; H, 3·5%).

4 : 9-Dimethyloctalin after three passages over platinum (1) at 330° gave 40% of gas and a product which, when cooled in ice and salt, deposited 1 : 5-dimethylnaphthalene, m. p. 77°, not depressed by authentic material, but depressed by admixture with naphthalene (Found : C, 92·2; H, 7·9. Calc. for $C_{12}H_{12}$: C, 92·25; H, 7·75%). It gave a yellow picrate, m. p. 137° (Found : C, 55·7; H, 4·0. Calc. for $C_{18}H_{15}O_7N_3$: C, 56·1; H, 3·9%). The liquid, after the

removal of the 1 : 5-dimethylnaphthalene, yielded a dimethylnaphthalene picrate which crystallised from alcohol in long orange-red needles, m. p. 133—134°. After several crystallisations the m. p. rose to 134—134·5°, but not further (Found : C, 55·7; H, 3·9%). This orange picrate yielded a liquid hydrocarbon on regeneration with ammonia. The corresponding styphnate was yellow, m. p. 145°.

4 : 9-Dimethyloctalin after one passage over palladium (1) at 330° gave 70% of gas, and a product depositing no solid in ice and salt. The main product was α-methylnaphthalene, isolated as the picrate. This had m. p. 138°, and appeared to contain a little dimethylnaphthalene picrate, which could not be separated by crystallisation (Found : C, 55·4; H, 3·9%). A little of the orange (dimethylnaphthalene) picrate, m. p. 134°, was also isolated.

4 : 9-Dimethyldecalin over platinum (1) at 330° gave 55% of gas in two passages, solid 1 : 5-dimethylnaphthalene (main product), and a little of the orange picrate, m. p. 134°. The same hydrocarbon over palladium (1) at 330° gave 70% of gas, and α-methylnaphthalene (main product), the picrate of which melted at 138°, raised by admixture with an authentic sample (Found : C, 55·3; H, 3·9%). 1 : 5-Dimethylnaphthalene (m. p. and mixed m. p. 76°) and the orange picrate, m. p. 134°, were isolated as by-products. The orange picrate was less soluble in alcohol than that of α-methylnaphthalene.

V. *Dehydrogenation of Methyloctalins obtained by Direct Cyclisation.*—5 G. of methyloctalin, made by dehydration of 1-methyl-2-butenyl*cyclo*hexanol (J., 1936, 470), was dehydrogenated in the vapour phase over palladium (1) at 330°. It yielded 90% of gas in one passage, but only 3·4 g. of liquid product were recovered. This was separated into naphthalene (1·4 g., m. p. 78°) and 1-methylnaphthalene (*ca.* 1·6 g.; picrate, m. p. 140°; styphnate, m. p. 136°). Over platinum (1) at 330° the same hydrocarbon yielded 45% of gas, 1-methylnaphthalene (picrate, m. p. 140°; styphnate, m. p. 136°; mixed m. p.'s the same), and no naphthalene (Found for the picrate : C, 55·1; H, 3·8. Calc. for $C_{17}H_{13}O_7N_3$: C, 55·0; H, 3·5%). Over palladium (1) at the b. p. in the liquid phase this methyloctalin gave only 1% of hydrogen in 210 minutes and hence was essentially a 9-methyl compound.

The following experiment was carried out by Dr. D. C. Hibbit : Methyloctalin from 1-methyl-2-butenyl*cyclo*hexanol, after one passage over freshly prepared platinum (1), gave 51% of solid naphthalene (picrate, m. p. and mixed m. p. 149°).

Methyloctalin, made by dehydration of 2-methyl-1-butenyl*cyclo*hexanol (J., 1936, 476), over palladium (1) at 330° gave 75% of gas, solid naphthalene (m. p. and mixed m. p.), and a little α-methylnaphthalene. After dehydrogenation over platinum (1) at 330° the only isolable product was α-methylnaphthalene (picrate, m. p. 140°. Found : C, 54·95; H, 3·90%). This methyloctalin, when boiled with palladium (1), yielded a maximum of 14% of hydrogen and 20% of α-methylnaphthalene. The residual non-aromatic hydrocarbon was mainly saturated. Hence this methyloctalin was a mixture of the 1- and the 9-methyl compound.

VI. *Synthesis of Dimethylnaphthalenes.*—1 : 5-*Compound.* β-*o*-Tolylethyl alcohol (28 g.), b. p. 113—117°/9 mm., was prepared from the Grignard compound made from 52 g. of *o*-bromotoluene and ethylene oxide. The corresponding bromide, prepared in good yield by the action of phosphorus tribromide in carbon tetrachloride, boiled at 104—106°/9 mm., and on treatment with sodiomalonic ester in toluene yielded ethyl β-*o*-tolylethylmalonate, b. p. 150—155°/1·5 mm. Hydrolysis and distillation yielded γ-*o*-tolylbutyric acid, b. p. 145°/1 mm., m. p. 58°. Harvey, Heilbron, and Wilkinson (J., 1930, 423) give m. p. 60°. The acid was converted, following Harvey, Heilbron, and Wilkinson, successively into 5-methyl-1-tetralone, 1 : 5-dimethyl-3 : 4-dihydronaphthalene, and 1 : 5-dimethylnaphthalene.

1 : 8-*Compound.* *o*-Methylacetophenone (36 g.) was condensed with 70 g. of ethyl bromoacetate and 35 g. of zinc in 250 c.c. of benzene, and the product distilled with a little iodine. The β-*o*-tolylcrotonic ester obtained (45 g., b. p. 144—148°/18 mm.) was reduced in the usual way with 80 g. of sodium in 750 c.c. of calcium-dried alcohol, and the γ-*o*-tolylbutanol isolated by distillation in steam and under reduced pressure (b. p. 140—145°/18 mm.; yield, 23 g.). This was converted through the bromide and nitrile in the usual manner into γ-*o*-tolylvaleric acid (9·9 g.), b. p. 150°/1 mm., which failed to solidify in ice. The chloride of this acid was cyclised by means of aluminium chloride in carbon disulphide to 4 : 5-*dimethyl*-1-*tetralone*, which solidified after distillation (b. p. 154—156°/18 mm.) and was crystallised from methyl alcohol. Yield, 8 g.; m. p. 56° (Found : C, 82·3; H, 8·3. $C_{12}H_{14}O$ requires C, 82·7; H, 8·1%). The ketone (7 g.) was reduced by means of sodium (10 g.) in alcohol (200 c.c.), the solvent removed in steam, and the residue isolated by means of ether. After distillation with a crystal of iodine, 4·5 g. of 1 : 8-*dimethyl*-1 : 2-*dihydronaphthalene* were obtained, b. p. 116°/18 mm. This was dehydrogenated with selenium at 300° for 12 hours. The 1 : 8-*dimethylnaphthalene*

solidified after distillation (b. p. 140°/18 mm.) and formed white leaflets from dilute alcohol, m. p. 63° (Found : C, 92·2; H, 7·7. $C_{12}H_{12}$ requires C, 92·25; H, 7·75%).

1 : 2-Dimethylnaphthalene was prepared by the method of Mayer and Sieglitz (*Ber.*, 1922, 55, 1851), and the 1 : 4-isomeride by the method of Robinson and Thompson (J., 1932, 2015). The properties of these dimethylnaphthalenes and their derivatives are summarised in Table I. The orange-red picrate, m. p. 134°, and the yellow styphnate, m. p. 145°, obtained from the by-product of the dehydrogenation of 4 : 9-dimethyl-octalin and -decalin, resembled the corresponding derivatives of 1 : 2-dimethylnaphthalene. Mixtures of the two picrates and the two styphnates, however, showed considerable depressions of m. p.

SUMMARY.

1. Tetralins and polycyclic compounds containing the tetralin structure are readily and quantitatively dehydrogenated over platinum and palladium at the boiling point; the evolution of hydrogen measures the degree of separation from the aromatic state.

2. Octalins readily disproportionate over these catalysts at the boiling point into the corresponding decalins and tetralins, the latter of which are then dehydrogenated. Octalins can therefore be dehydrogenated at comparatively low temperatures to give moderate yields of naphthalenes. They are dehydrogenated to give good yields of naphthalenes at 300° and above.

3. Decalins are very slowly dehydrogenated at the boiling point, but readily at 300° and above.

4. 1- and 2-Methyl groups remain intact in all these reactions.

5. When an angular methyl group is present, there is no dehydrogenation or disproportionation at about 200°. At about 300° the compound is dehydrogenated; the angular group either is eliminated or migrates to the α-carbon atom, according to the catalyst.

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242. *Leucoanthocyanins. Part III. Formation of Cyanidin Chloride from a Constituent of the Gum of* Butea Frondosa.

By (MRS.) G. M. ROBINSON.

Leucoanthocyanins occur widespread in plant material, but the anthocyanidins into which they may be converted have hitherto been identified by means of a system of qualitative tests and comparisons in solution. It is now shown that the gum of *Butea frondosa* contains a substance that can be converted into cyanidin chloride, and the anthocyanidin has been isolated, analysed and compared with an authentic specimen. Cyanidin is not formed from the gum by the action of hydrochloric acid alone; preliminary oxidation is necessary and under special conditions the use of picric acid has been found to be advantageous.

ALTHOUGH it is thought that the qualitative examination of anthocyanins and anthocyanidins by the methods of Robinson and Robinson (*Biochem. J.*, 1931, 25, 1687; 1932, 26, 1647) affords reliable results, this type of investigation has obvious limitations and is no substitute for the more precise and formal study of the pigments isolated in a pure condition. The two methods are complementary and the value of the qualitative tests as an auxiliary resides in the power that they confer of covering a wide range, a particularly useful application being the analysis of anthocyanins in varieties of the same species in connection with genetical investigations.

The anthocyanidins derived from the widely distributed leucoanthocyanins (Robinson and Robinson, *Biochem. J.*, 1933, 27, 206) were examined by the qualitative methods alone and, in general, the behaviour of the colouring matters tallied with that of the known anthocyanidins of flower pigments. In this case, however, the background of

systematic investigation was lacking and it was therefore deemed desirable to attempt the isolation of the presumed anthocyanidins from typical leucoanthocyanins. Experimentally the problem proved to be a difficult one and several rich sources of leucoanthocyanins were found in preliminary work to be unsuitable. Eventually the gum of *Butea frondosa* (Bengal kino) was selected and, although all attempts to isolate the leucoanthocyanin itself have been fruitless, conditions have been found which promote the formation of cyanidin chloride from it.

If the gum is boiled in an open vessel with aqueous or alcoholic hydrogen chloride, some colouring matter of anthocyanidin type is produced, but if air is carefully excluded a red coloration is observed which is not due to anthocyanidin. The colouring matter formed in the latter way gives a characteristic violet solution in aqueous sodium carbonate. Aerial oxidation is nevertheless unsatisfactory and, although more colouring matter is produced by boiling with concentrated hydrochloric acid along with acetone, ethylene glycol or glycerol, the cyanidin appears to be modified in these cases. Bromine as an oxidant gives good results, but this method was not adopted in view of the risk of nuclear bromination.

Treatment of the gum with boiling saturated aqueous picric acid (not effective in the presence of hydrochloric acid) brings about a change that facilitates the subsequent formation of anthocyanin and ultimately a preliminary treatment with aqueous sodium acetate and zinc chloride was found to be advantageous.

The cyanidin chloride, isolated as explained in the experimental section, was persistently contaminated with a colourless by-product. The composition of this must be closely similar to that of cyanidin chloride, because a specimen containing only about 67% of the anthocyanidin gave approximately correct results on analysis.

The fully purified cyanidin chloride showed all the characteristic properties of authentic specimens of the natural and the synthetic anthocyanidin and no divergence was observed in any respect. Direct comparisons of distribution ratios and colorations in solutions of definite p_H were carried out.

EXPERIMENTAL.

Preliminary Experiments.—The gum of *Butea frondosa*, as supplied by Messrs. British Drug Houses, Ltd., is moderately easily soluble in boiling water, probably in part in the colloidal state; on drying at 100° it becomes insoluble in boiling water. Also when the dried kino is extracted in a Soxhlet apparatus with benzene or acetone, only a small quantity of waxy matter passes into solution. The prolonged action of cold 10% alcoholic hydrogen chloride on the gum results in the formation of a deep red solution, from which ether extracts a yellow substance (bright red coloration in sulphuric acid) and then ethyl acetate extracts a red substance which dissolves in aqueous sodium carbonate to a violet solution and in aqueous sodium hydroxide to a blue solution. This is not a known anthocyanidin, although it may well be a related substance.

If the gum is heated with 5·5% alcoholic hydrogen chloride, the same colouring matter is produced along with a substance exhibiting a bright blue fluorescence. The latter is removed from an amyl-alcoholic solution by aqueous sodium carbonate but not by aqueous sodium hydrogen carbonate. Prolonged boiling with hydrochloric acid results in the formation of a little anthocyanidin, but, as already explained, some pre-treatment is essential and picric acid was found to give the best results.

The gum was boiled with saturated aqueous picric acid, the mixture concentrated on the steam-bath, washed with benzene, and heated with alcoholic hydrogen chloride. The anthocyanidin was isolated as described below except that the washing with hot ethyl acetate was omitted because the necessity for it was not realised at this stage. The flat needles from 7% methyl-alcoholic hydrogen chloride had the appearance of cyanidin chloride (Found: C, 53·5; H, 4·6; Cl, 9·5%). Colorimetric comparisons showed that this specimen contained 66·6% of cyanidin chloride; the distribution ratios tallied with those of cyanidin chloride after adjustment of the concentrations of the solutions so as to obtain colorimetric equivalence.

Isolation of Cyanidin Chloride.—A mixture of the finely powdered gum (2·0 g.; larger quantities give poorer results) with water (30 c.c.) and crystallised sodium acetate (2·5 g.) was boiled for 10 minutes; powdered zinc chloride (3 g.) was then added, and boiling continued for 1 minute. The solid was collected and refluxed with cold-saturated aqueous picric acid

(14 c.c.) for 8 minutes; almost the whole had then passed into solution. Alcoholic hydrogen chloride (250 c.c. of 5·5%) was added, and refluxing continued for 30 minutes, the liquid becoming dark red. Finally, after the addition of 5% hydrochloric acid (50 c.c.), the liquid was boiled for 15 minutes. The product was diluted with twice its volume of water, washed repeatedly with benzene, and extracted with amyl alcohol. The separated organic layer was shaken with water containing a trace of hydrochloric acid, and light petroleum added. The aqueous solution was successively washed with ether, ethyl acetate, and benzene, aqueous picric acid was added, and on keeping in the ice-box cyanidin picrate (0·19 g.) separated in slender needles. By working up the aqueous solution, a further quantity of picrate (0·09 g.) was obtained as well as cyanidin chloride (0·03 g.). The latter was isolated, after no further picrate separated, by several transferences of the chloride from hydrochloric acid to amyl alcohol and vice versa and finally by precipitation from an aqueous solution by the addition of concentrated hydrochloric acid. The product gave the usual reactions for cyanidin chloride.

The fact that the gum contains about 5% of moisture and about 15% of inorganic matter (mainly sodium silicate with magnesium, potassium, calcium, and iron) being taken into consideration, the yield of cyanidin chloride was about 14% of the weight of the dry, ash-free gum. This is only a rough estimate, but is probably an understatement in view of the inevitable losses sustained in the isolation processes. The picrate was converted into chloride and regenerated in aqueous solution. It was then dissolved in 7% methyl-alcoholic hydrogen chloride, and the solution concentrated under diminished pressure. The crystals of cyanidin chloride were collected and washed with ether and with cold and *hot* ethyl acetate; the substance was again crystallised from 7% methyl-alcoholic hydrogen chloride and washed as before. The washing with hot ethyl acetate removes a colourless substance. This gave no characteristic colour reaction in acid or alkaline solution, but on heating a red coloration was developed in both cases. The cyanidin chloride was dried in a vacuum desiccator at room temperature (Found: C, 52·9; H, 4·1; Cl, 10·1; MeO, 0·0. Calc. for $C_{15}H_{11}O_6Cl,H_2O$: C, 52·9; H, 3·8; Cl, 10·4%). The flat, microscopic needles were chocolate-brown in mass and orange-red by transmitted light; they exhibited all the characteristics and reactions of cyanidin chloride.

Comparison with a Specimen of Cyanidin Chloride from Cyanin Chloride.—The specimen (*B*) from the gum was dried over potassium hydroxide in a desiccator, but at the ordinary pressure; it was probably hydrated to a slight extent. Colorimetric comparison with a very pure specimen of cyanidin chloride (*C*) from cyanin which had been completely dried showed that (*B*) had 95% of the pigment content of (*C*). After the small corresponding adjustment of the concentration of the solutions in 0·5% hydrochloric acid (6·099 mg. in 50 c.c.) they were colorimetrically identical.

In making up the solutions it was noted that both were more intensely coloured when cold than when hot and to the same extent. Addition of alcohol produced the same blueing effect in each case. The following distribution ratios were compared, equal volumes of organic solvent and aqueous solution being used; the organic layers were directly compared and no divergence exceeding 0·4% was observed in the colorimeter: *cyclo*hexanol–toluene (1 : 5), *cyclo*hexanol–toluene (1 : 4), *cyclo*hexanol–benzene (2 : 3), ethyl acetate. In the case of the specimen, mentioned above, containing 66·6% of cyanidin chloride a few more solvents were employed with the same result.

The behaviour with ether–picric acid, sodium acetate, sodium carbonate, sodium hydroxide, ferric chloride, amyl alcohol–sodium acetate–ferric chloride, and concentrated sulphuric acid was identical with (*B*) and (*C*). In the latter case the slow development of a weak green fluorescence was observed and the rate of appearance, colour, and intensity of the fluorescence were indistinguishable.

Dilute aqueous ferric chloride (the bench reagent) was diluted five-fold, and 10 c.c. added to 20 c.c. of each of the solutions diluted with 80 c.c. of 0·5% hydrochloric acid at 17·5°. The solutions showed an identical behaviour; after mixing they became slightly deeper in colour and tinged violet. After 15 minutes the colour was almost discharged and after 30 minutes the solutions were colourless. Addition of concentrated hydrochloric acid did not restore the colour, but gave a yellow solution due to the ferric salt alone, as was proved by a parallel experiment without cyanidin. The colours developed in two ranges of buffered solutions were also observed and no divergences were noted (cf. Robertson and Robinson, *Biochem. J.*, **1929**, **23**, 35). The ranges used were of p_H 3·1, 4·3, 5·5, 6·65, 7·8, 9·0, 10·2, 11·4 and 3·1, 3·34, 3·58, 3·82, 4·05, 4·29, 4·53 and 4·77; the latter range was used to observe the rate of formation of

the ψ-base. This was very slow at p_H 3·1 but rapid at p_H 3·3 and most rapid at about p_H 3·6; with increasing p_H complete decolourisation occurred up to p_H 4·8 in 30 minutes, but at p_H 5·0 a pale colour remained after this period. Addition of hydrochloric acid restored the colour in all cases to the same extent, but after the solutions had been kept for 15 minutes or more they had to be boiled in order to produce regeneration of the oxonium salt.

These results prove that the pigment isolated after treating the gum of *Butea frondosa* in the prescribed manner is cyanidin chloride. The difficulties in the purification do not arise from the necessity for separating two anthocyanidins but from the presence of impurities of an entirely different character.

Notes on Occurrence of Leucoanthocyanins.—In addition to the sources already disclosed (*loc. cit.*), the following observations have been made by means of the method of qualitative tests. The conclusion previously reached that the majority of leucoanthocyanins yield cyanidin has been confirmed. Instead of treating the materials with hot hydrochloric acid, it is now preferred to use boiling 5% alcoholic hydrogen chloride. Cyanidin chloride is derived from the woods of *Endriandrh Palmerston* (Queensland walnut) and *Eucalyptus tereticornis* (also *Eucalyptus kino*). All parts of *Hypericum calycinum* (St. John's wort) and especially the young seed pods contain a leucoanthocyanin yielding cyanidin. *Krameria* root, on the other hand, contains a leucoanthocyanin yielding pelargonidin, and *Quillia* shavings and *Musa sapientum* (banana) contain leucoanthocyanins yielding delphinidin. In the last case the leucoanthocyanin is contained in the fibres forming part of the meal. The fleshy part of the fruit was washed with alcohol and water; the residue, on boiling with alcoholic hydrogen chloride, afforded delphinidin chloride. Several of the materials tested (*e.g.*, *Krameria* and *Quillia*) have been found to contain much phosphate.

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243. *Experiments on the Synthesis of Substances related to the Sterols. Part XVII. 8-Methylhydrindan-1-one.*

By ROBERT ROBINSON and JAMES WALKER.

Owing to the anticipation of work already published in part, an account is submitted of the synthesis of 8-methylhydrindanone from ethyl 2-methyl*cyclo*hexanone-2-carboxylate. A side chain is introduced by means of the Grignard reaction and the product is suitably modified so as to obtain a dicarboxylic acid, from which the ketone is readily obtained by the known method.

IN a paper submitted on December 14th, 1936, and published in the January number of the *Journal* (this vol., p. 60), we described the first stages of a new method for the construction of ketones containing angular methyl groups and stated that further investigation of the subject was in progress. The remaining processes of a more routine character were studied without undue loss of time and are described below.

In the meantime, Kon, Linstead, and Simons, in a paper (this vol., p. 814) submitted six weeks after the publication of ours, have described the same method (ethoxyl instead of methoxyl) and an acknowledgment is contained in a footnote. We fully recognise the independent nature of the work of these authors and at the same time claim as much for our own. A statement that the ketone had been made was included in a contribution to a discussion at the Chemical Society on May 20th. Consequently we are compelled to submit an account of the completion of this part of our researches leading to the preparation of a ketone first described by Chuang, Tien, and Ma (*Ber.*, **1936**, **69**, 1494). In view of the recent publication of Kon, Linstead, and Simons (*loc. cit.*) a further theoretical description is unnecessary. It only remains to add that the process of these authors for the dehydration of the carbinol is superior to ours and on the other hand our overall yield in the three last stages is about twice as great as theirs.

EXPERIMENTAL.

*Ethyl 2-Methyl-1-γ-methoxypropyl*cyclo*hexane-2-carboxylate.*—The divergence in the analytical figures from the anticipated values as previously recorded (this vol., foot of p. 65) was actually

due to contamination with a small amount of the carbinol. The hydrogenated material (*loc. cit.*) (4·9 g.) was heated with potassium hydrogen sulphate (10 g.) for 3 hours at 180—190°, and the recovered material distilled (4·5 g.) at 138—142°/12 mm.; $n_D^{14°}$ 1·4582. Hydrogenation was effected as before in methyl alcohol (70 c.c.) with palladised strontium carbonate (6 g.) under pressure for 16 hours. The saturated material (4·2 g.) was a colourless mobile oil, b. p. 138—140°/12 mm., $n_D^{14°}$ 1·4588 (Found: C, 69·1; H, 10·7. $C_{14}H_{26}O_3$ requires C, 69·4; H, 10·7%).

Ethyl 2-*Methyl*-1-γ-*hydroxypropyl*cyclo*hexane*-2-*carboxylate*.—The foregoing compound (4·0 g.) was dissolved in acetic anhydride (25 c.c.) saturated below 0° with hydrogen bromide and the solution was left for 5 days in the ice-chest. The resulting clear, almost colourless solution was mixed with ice-water and extracted with ether. The extract was well washed with sodium carbonate solution, dried, and evaporated. The crude neutral material (4·2 g.) contained bromine and was heated with anhydrous potassium acetate (7 g.) in glacial acetic acid (10 c.c.) on the steam-bath for 5 hours. The recovered material still contained bromine and the treatment with potassium acetate was repeated under reflux. The halogen-free product (4·07 g.) was refluxed for 6 hours with 2·5% methyl-alcoholic potassium hydroxide (50 c.c.); the neutral material (3·3 g.), isolated in the usual way, distilled (2·72 g.) as a colourless limpid oil at 160—165°/13 mm.; $n_D^{16°}$ 1·4725 (Found: C, 68·5; H, 10·5. $C_{13}H_{24}O_3$ requires C, 68·4; H, 10·5%).

2-*Methyl*cyclo*hexane*-2-*carboxylic*-1-β-*propionic Acid*.—The above ester was not readily hydrolysed. The ester (2·6 g.) was refluxed for 30 hours with baryta (3·7 g.; large excess) in 50% methyl alcohol (30 c.c.), and the product separated into acidic (1·3 g.) and neutral (1·1 g.) portions. The latter was refluxed for 30 hours with alcoholic potassium hydroxide (2 g. of potassium hydroxide in 10 c.c.), and the acidic material recovered added to that previously obtained (total, 2·18 g.); it was a colourless syrup which did not crystallise. Oxidation was effected with the theoretical amount of potassium permanganate (2·28 g.) in water, added to a solution of the hydroxy-acid (2·18 g.) in aqueous sodium carbonate (1·3 g. in 4 c.c.). The mixture was left at room temperature until the colour of the permanganate disappeared (2 days), filtered, and the hot water washings of the residue added to the filtrate. After acidification the dibasic acid was extracted with ether and recovered (1·88 g.) as an exceedingly viscous, colourless syrup. It showed no signs of crystallisation after 2 days in the ice-chest and was characterised by the following experiment.

8-*Methylhydrindan*-1-*one*.—The above dibasic acid (1·88 g.) was distilled with baryta (120 mg.) at 300—320° until reaction appeared to be complete (*ca.* 1 hour) and distillate and residue were worked up for neutral product in the normal way by extraction with ether. The crude product (1·14 g.) was distilled in a vacuum; the ketone (0·67 g.; 50%), collected at 93—95°/18 mm., solidified to a colourless waxy solid; it had a pronounced odour of camphor and could just be melted by the warmth of the hand (Found: C, 78·8; H, 10·6. $C_{10}H_{16}O$ requires C, 78·9; H, 10·5%). The *semicarbazone* had m. p. 221—222° after one recrystallisation from aqueous alcohol (Found: C, 63·5; H, 9·1. $C_{11}H_{19}ON_3$ requires C, 63·2; H, 9·1%).

Dyson Perrins Laboratory, Oxford University. [*Received, June 9th*, 1937.]

244. *The Heat of Decomposition of Dichlorine Heptoxide.*

By Charles F. Goodeve and Arthur E. L. Marsh.

A Knowledge of the heats of decomposition of the oxides of chlorine is of great value in interpreting the processes of their thermal and photochemical decomposition. The heats of decomposition of chlorine monoxide and dioxide have been determined by a number of investigators but no value has been published for dichlorine heptoxide. That of the monoxide has been deduced both from its heat of solution in potassium iodide by Berthelot ("Thermochemische Messungen," Leipzig, 1893), Thomsen ("Thermochemistry," 1908), Neumann and Müller (*Z. anorg. Chem.*, 1929, **182**, 235), and from direct measurements of its heat of explosion by Mayer (Diss., Hanover, 1924), Gunther and Wekua (*Z. physikal. Chem.*, 1931, **154**, 193), and Wallace and Goodeve (*Trans. Faraday Soc.*, 1931, **27**, 648). The heat of decomposition of chlorine dioxide was first determined directly as the heat of explosion, by Booth and Bowen (*J.*, 1925, **127**, 342), using a carbon dioxide–chlorine dioxide mixture, and by Wallace and Goodeve (*loc. cit.*), using the pure vapour.

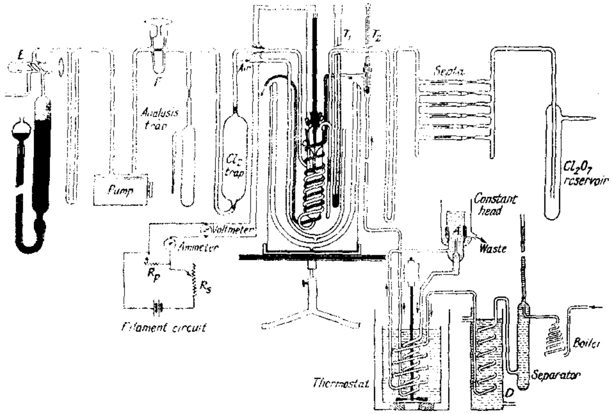
There is no convenient indirect method of measuring the heat of decomposition of chlorine heptoxide, and an indirect method has the disadvantage that experimental error is greatly magnified because the final result is obtained as a small difference between two large quantities.

In the method adopted, gaseous heptoxide was decomposed directly into its elements by streaming it continuously over a red-hot platinum filament. The decomposition could be carefully controlled to avoid lower oxides in the final products. This method has apparently not been used before for thermochemical determinations and may have wider application than that given here.

EXPERIMENTAL.

After a number of preliminary trials the final apparatus was constructed as shown in Fig. 1. The heptoxide from the reservoir passed to the decomposition chamber through a bank of septa,

FIG. 1.



which took the place of a tap, and through a U-tube immersed in water to ensure that it was at the temperature of the calorimeter. The vapour was decomposed as it streamed through a fine jet, down the centre of which was the heated filament. The heat generated by this filament was compensated by means of a cooling coil of lead "Compo" tubing (shaded in the figure), through which flowed a steady stream of cold water. The chlorine resulting from the decomposition was frozen out in a liquid-air trap for subsequent analysis, and the oxygen collected in a graduated eudiometer tube.

The decomposition chamber was made entirely of Monax glass, and was connected to the rest of the apparatus (of soda glass) by two ground-glass joints. The chlorine heptoxide vapour entered through a U-tube in which was a 1·5-cm. length of fine sand fixed securely between two glass-wool plugs; this served to prevent the frequent explosions which occurred during the decomposition passing back to the heptoxide reservoir: when the length was reduced to about ¾ cm. an explosion did pass back to the reservoir. The jet was 1 mm. in bore and 2 cm long. The platinum filament (0·1 mm. in diameter and 2·5 cm. long) was connected between two thick platinum leads (1 mm. diameter) and was replaced when necessary by dissembling the apparatus at the ground-glass joints *b* and *c*. These joints were lubricated with graphite and a trace of metaphosphoric acid, and made vacuum-tight with picene wax. Several coatings of seccotine were applied to the picene owing to the solubility of the latter in the toluene, used for the calorimeter liquid. A pint-size Dewar vessel was used as a calorimeter, and stirring was effected by

its rotation at constant speed (100 r.p.m.). Vertical stirring was assisted by an air pump, the air having been previously saturated with toluene at the temperature of the calorimeter. The Beckmann thermometer T_1 was read to 0·001° with a telescope. In order to prevent the mercury thread sticking, the thermometer was automatically shaken by an electromagnetic hammer, contacts being arranged on the turn-table. The shaking could be interrupted for readings by means of a tapping-key.

The chlorine trap contained a 3-mm. layer of fine sand to prevent crystals of chlorine being swept through by the oxygen stream. The sand was kept in place by a plug of glass-wool sintered into the base of the trap. A second plug sintered into the top of the trap prevented particles of sand from being blown back into the decomposition chamber on admission of air into the apparatus between experiments. The tap F did not come in contact with heptoxide and, therefore, graphite and metaphosphoric acid could be used as a lubricant.

The pump used was of the Gaede type, and was fitted with special gaskets of glue–glycerol composition to make it air-tight. There was a considerable volume of air above the oil in this pump, which consequently had to be turned on about an hour before an experiment was carried out in order to allow it to reach an equilibrium temperature.

The eudiometer tube was graduated in 0·2 c.c. and could be read to 0·1 c.c. A sulphuric acid differential manometer was connected to the eudiometer tube to facilitate the adjustment of the oxygen to atmospheric pressure.

Electrical Circuit for Platinum Filament.—When the apparatus was evacuated, a current of about 0·9 amp. and a potential drop of about 2 volts were sufficient to keep the filament at a bright-red heat, 800—900° (the temperature was calculated from the change of resistance). As soon as the decomposition commenced, however, the heat conducted away from the filament by the gases surrounding it was considerable, and the temperature of the filament fell to 400—500°. This fall in temperature was accompanied by a corresponding fall in the resistance of the filament, so that, if constant voltage was maintained, the wattage increased considerably. This difficulty was overcome by placing a resistance R_s in series with a 4-volt supply, and a further resistance R_p in parallel with the filament. By adjustment of R_s and R_p, the circuit could be so balanced that, when the temperature of the filament fell, the increased current was counteracted by a proportionate fall in the voltage across the filament. The values of R_s and R_p were approximately 1·5 and 20 ohms respectively. This circuit could not be perfectly adjusted, however, and readings of current and voltage had to be taken at minute intervals throughout the experiment. Standardised Weston instruments were used. By plotting the current–voltage product against the time, a correction could be applied for any slight increase or decrease of wattage.

Cooling System.—In order to ensure a steady flow of water at constant temperature through the compensating cooling coil, the water first had to be boiled to remove dissolved gases, its rate of flow controlled by a constant-head device, and its temperature thermostatically controlled just before it entered the cooling coil. Tap-water was boiled in a cone-shaped spiral of "Compo" tubing, whence it passed into the separator where the liberated gases were removed. It was then rapidly cooled to the temperature of tap-water in the vessel D. It now passed through the outer coil of "Compo" tubing in the thermostat, providing the necessary cooling effect for control of the latter at 13°. From this coil the water entered the constant-head device by the side-tube, the greater part of it going to waste while a constant stream passed on to the inner coil of the thermostat. Its rate of flow was roughly controlled by the narrow constriction, A, fine control being provided by variation of the head of water in the concentric tubes.

The thermostat consisted of a 4-litre beaker resting on an asbestos ring in a chromium-plated vessel, and the thermoregulator was made of 20 ft. of glass tubing coiled around the inside of the beaker and filled with xylene. No relay was used, a small heater in series with a 25-c. p. carbon-filament lamp being connected in parallel with the platinum contacts of the thermoregulator. The thermostat was filled with kerosene on account of its good insulating properties and low viscosity. A very fast stirrer was used.

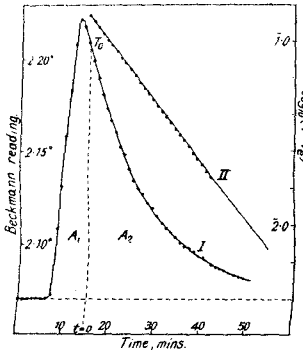
The inner coil of the thermostat was connected to the cooling coil in the calorimeter by a short length of pressure tubing which was well lagged with asbestos-wool. The temperature of the water was observed just before it entered the cooling coil by means of the Beckmann thermometer T_2. Despite the thorough lagging of the pressure tubing, the temperature of the water was very sensitive to changes of room temperature, and consequently all experiments had to be conducted in a room the temperature of which (20°) was thermostatically controlled to within 0·1°. Calculations from heat-conductivity data showed that, at the rate of flow used (about 2 c.c./min.), the temperature of the water on leaving was equal to that of the calorimeter.

Procedure.—At the beginning of an experiment the apparatus was completely evacuated,

the tap E being open to the atmosphere. Liquid air was placed round the chlorine heptoxide reservoir and on the chlorine trap, and a septum was broken. Care was taken before the experiment that the cooling system was completely free from air bubbles, these having a serious effect on the rate of flow of the water. The rotating calorimeter and its cooling system were then started. The cooling effect of the water being proportional to the difference between the temperatures of the calorimeter and cooling coil, an equilibrium temperature was reached where the cooling effect of the water was equal to the heating effect of the filament. After the preliminary experiments, the equilibrium temperature was known to within a few hundredths of a degree and could, therefore, be quickly attained by a temporary increase or decrease of the cooling effect.

As soon as equilibrium temperature had been reached, tap E was rotated, and the liquid air round the heptoxide reservoir was replaced by a water-bath at about 15° (equilibrium vapour pressure = 52 mm.). A higher reservoir temperature, causing a more rapid flow of heptoxide, resulted in only partial decomposition, and in some of the preliminary experiments a dark ring of dichlorine hexoxide was observed in the chlorine trap after the experiment. Readings of the temperatures of the calorimeter and cooling water, and of the current and voltage of the filament, were taken at minute intervals.

FIG. 2.



I. The temperature-time curve of the calorimeter for experiment B.5.
II. The corresponding $\log_{10}(T - T_e)$ curve.

When sufficient heptoxide had been decomposed, the distillation was stopped by cooling the heptoxide reservoir to − 78° in carbon dioxide–alcohol for a minute and then to − 180° by liquid air. If the distillation was stopped by sudden cooling in liquid air, chlorine tended to diffuse back from the decomposition chamber, and resulted in a low chlorine analysis.

Readings were continued for a further 20 minutes, the cooling of the calorimeter being followed back almost to equilibrium temperature. At the end of an experiment, the broken septum was sealed off at the constriction, and the tap F closed. The chlorine was distilled into the analysis trap, sealed off, and subsequently determined by breaking the jet beneath potassium iodide solution and titrating the free iodine against $N/10$-sodium thiosulphate.

The heat capacity of the calorimeter was determined electrically in the usual way, the filament being used as the heating resistance.

Theory of Method.—The temperature–time curves obtained by the above procedure were of the type shown in Fig. 2 (curve I). The temperature is dependent on the rate of heat production in the filament, the rate of removal of heat by the cooling water, and the heat produced by the decomposition of the heptoxide. The first is given by the equation

$$dq/dt = IV/4{\cdot}18, \text{ cals. per sec.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where I is the current through the filament and V the potential across the leads. The cooling water on passing through the calorimeter is raised from T_w, its temperature just before entering, to T, the temperature of the calorimeter. "The cooling effect," *i.e.*, the heat removed from the calorimeter (per second), is proportional to the difference in temperature and is given by

$$dq/dt = -c_w(T - T_w)dm/dt \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where c_w is the specific heat of water per gram, and dm/dt the rate of flow. Other heat effects, such as those from the stirrer or from conduction, were either constant or varied linearly with temperature and are included in equations (1) and (2).

In the absence of inconstant heating effects the temperature reaches an equilibrium value, T_e, given by the equation

$$dq/dt = IV/4{\cdot}18 - c_w(T_e - T_w)dm/dt = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

If now a quantity of heat, q_D, arising from a chemical reaction, is absorbed by the calorimeter, the temperature will rise, but as the cooling effect will also increase, it will finally be brought back to its equilibrium value as shown in Fig. 2. The quantity of heat, q_D, will then have been completely removed by the *extra* cooling effect occurring while the temperature is above the equilibrium value. This extra cooling effect is obtained by subtracting equation (3) from the generalised equation obtained by adding equations (1) and (2):

$$dq/dt = -c_w(T - T_e)dm/dt \qquad (4)$$

This, on integration, gives

$$q_D = -\int dq/dt = c_w dm/dt \int (T - T_e)dt = k\int (T - T_e)dt \qquad (5)$$

We thus have the heat absorbed by the calorimeter given in terms of a constant, $k = c_w(dm/dt)$, multiplied by the area under the curve.

The constant can be evaluated by making use of the equation $dq/dt = C \cdot dT/dt$, where C is the heat capacity of the calorimeter. Equation (4) on rearrangement can be integrated for the cooling part of the curve, giving

$$\log (T - T_e) = -kt/C + \log (T_0 - T_e) \qquad (6)$$

where T_0 is the temperature at an arbitrary zero of time soon after the heating effect, due to the chemical reaction, has ceased. A plot of $\log_{10} (T - T_e)$ against t gives a straight line of slope $-k/2{\cdot}3C$ as shown in Fig. 2 (curve II). From an experimentally determined value of C and this slope, k is thus determined.

The area under the curve is divided into two sections A_1 and A_2, the division being effected at the time $t = 0$. As no simple equation fits the first part of the experimental curve, the area of section A_1 is determined by counting the squares on millimetre graph paper. The area of section A_2 is obtained from equation (6) by transformation into $T - T_e = (T_0 - T_e)e^{-kt/C}$ and *integration*:

$$A_2 = \int_0^\infty (T - T_e)dt = (T_0 - T_e)\int_0^\infty e^{-kt/C} \cdot dt = (T_0 - T_e)C/k \qquad (7)$$

On multiplying the total area $A_1 + A_2$, by k, the heat evolved by the chemical reaction is obtained. On dividing this by the fraction of a g.-mol. of heptoxide decomposed, the heat per g.-mol. is obtained. This is the value of ΔH, as the reaction is carried out at constant pressure. The temperature of the calorimeter was usually about 17°.

Results.—The results of 12 experiments on three separate preparations of heptoxide are given in the table. The values necessary for equation (5) are shown in cols. 2 and 3. The correction for changes in the wattage of the filament during the passage of the heptoxide gas is given in col. 4. This correction could be made to an accuracy of about 2% in the result. The values of ΔH calculated from both the oxygen and the chlorine analyses are given in cols. 7 and 8.

Expt. No.	Area under curve, ° C. secs.	$k \times 10$, cals./° C. sec.	$\Delta(IV)$ correction, cals.	Cl_2O_7 decomposed, millimols. From O_2.	From Cl_2.	ΔH, kg.-cals./g.-mol. From O_2.	From Cl_2.	Statistical weight.
A.1	225	1·61	−0·3	0·576	0·568	62·4	63·3	2
A.2	212	1·94	−1·4	0·579	—	68·6	—	1
A.4	119	2·30	−4·2	0·399	—	58·3	—	1
B.1	124	2·44	+0·6	0·433	0·430	71·3	71·9	3
B.2	—	—	+2·1	0·455	0·455	62·5	62·5	1
B.3	121	2·63	+1·8	0·538	0·538	62·8	62·8	4
B.4	153	1·71	−2·6	0·438	0·474	—	56·8	1
B.5	160	2·07	−2·2	0·493	0·481	62·7	64·4	2
C.1	245	1·38	−3·1	0·523	0·503	58·9	61·2	2
C.2	171	1·77	−0·6	0·506	0·511	—	59·0	3
C.3	167	1·79	0·0	0·458	0·472	—	65·9	2
C.4	136	1·84	−0·1	0·401	0·397	63·1	63·7	4

Weighted mean = 63·4

Owing to the necessary complexity of the apparatus, it was inevitable that the limits of error of the various experiments should differ considerably. The results have therefore been statistically weighted, as in the last column, on the following considerations. The calibration apparatus used for the first series was less accurate than that used for the second and third. The equilibrium temperature sometimes changed during the course of an experiment, due to permanent changes in the resistance of the filament, or to external influences. If such a change occurred

during the cooling part of the experiment, the accuracy of the results was little affected; if, however, it occurred during the heating period, as in experiment B.2, results could only be obtained by an extrapolation method, leaving large limits of error. The chlorine analysis failed in experiments A.2 and A.4 for mechanical reasons, thus preventing confirmation of the complete decomposition of the heptoxide. Traces of chlorine dioxide were found in the products from experiments B.4, C.2, and C.3, but the small correction could be calculated from the difference between the oxygen and chlorine analyses and the heat of decomposition of the dioxide.

It will be seen from the theoretical treatment that the temperature of the incoming cooling water need not be known, but must, of course, be constant. The variation of the filament and capillary temperatures during the passage of the gas produces no error, as their temperatures at the time $t = 0$ have returned to their initial values. At all events, the heat capacity of these parts is negligible.

The weighted mean for the heat of decomposition has been found to be 63·4 kg.-cals. per g.-mol. of dichlorine heptoxide with a probable error of 5% or ± 3 kg.-cals.

SUMMARY.

A new calorimetric technique for the study of gaseous reactions which take place only at high temperatures has been developed and applied to a study of the heat of decomposition of dichlorine heptoxide. The value of $\Delta H_{17°}$ for the reaction $Cl_2O_7 \longrightarrow Cl_2 + 3\frac{1}{2}O_2$ has been found to be − 63·4 ± 3 kg.-cals.

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245. *New Syntheses of* dl-*Thiolhistidine.*

By A. N. DEY.

ANY new method for the preparation of thiolhistidine, which has already been synthesised by Harington and his collaborators (J., 1930, 2586; *Biochem. J.*, 1933, **27**, 338), may have a possible significance for the ultimate synthesis of ergothioneine, to which it bears a close constitutional relationship. Two new methods for the preparation of *dl*-thiolhistidine are now recorded.

Ethyl αδ-diphthalimido-γ-keto-α-carbethoxyvalerate (II) obtained in poor yield by condensing *phthalo-ω-iodoacetonylimide* (I, X = I) with ethyl sodiophthalimidomalonate, on hydrolysis with concentrated hydrobromic acid gave the *dihydrobromide* of αδ-diamino-γ-ketovaleric acid, which when condensed with sodium thiocyanate formed *dl*-thiolhistidine:

$$\underset{\text{(I.)}}{R\cdot CH_2\cdot CO\cdot CH_2X} + CRNa(CO_2Et)_2 \longrightarrow \underset{\text{(II.)}}{R\cdot CH_2\cdot CO\cdot CH_2\cdot CR(CO_2Et)_2} \longrightarrow$$

$$NH_2\cdot CH_2\cdot CO\cdot CH_2\cdot CH(NH_2)\cdot CO_2H,2HBr \longrightarrow dl\text{-thiolhistidine}$$

$$(R = C_6H_4{<}{}^{CO}_{CO}{>}N;\ X = I, Br, \text{or } Cl.)$$

The same ester (II) was obtained, but in even smaller yield, when the corresponding chloro- or bromo-derivative (I, X = Br or Cl) was substituted for the iodo-compound.

In the second method, *δ-phthalimido-α-carbethoxy-γ-valerolactone* (III), obtained from phthalo-βγ-epoxypropylimide and ethyl sodiomalonate, was brominated, and the product hydrolysed and decarboxylated, giving the *bromo-lactone* (IV): this condensed with potassiophthalimide to furnish *αδ-diphthalimido-γ-valerolactone*, which on hydrolysis with potassium hydroxide gave αδ-bis-(*o*-carboxybenzamido)-γ-hydroxyvaleric acid (V). The corresponding keto-acid obtained by oxidation of the hydroxy-acid (V) with dilute potassium permanganate solution was hydrolysed with hydrochloric acid, and the resulting

dihydrochloride (VI) of αδ-diamino-γ-ketovaleric acid condensed with sodium thiocyanate, furnishing *dl*-thiolhistidine.

$$R{\cdot}CH_2{\cdot}\underset{O\text{———}CO}{CH{\cdot}CH_2{\cdot}CH}{\cdot}CO_2Et \longrightarrow R{\cdot}CH_2{\cdot}\underset{O\text{———}CO}{CH{\cdot}CH_2{\cdot}CHBr} \longrightarrow$$

(III.) (IV.)

(V.) $T{\cdot}CH_2{\cdot}CH(OH){\cdot}CH_2{\cdot}CHT{\cdot}CO_2H \longrightarrow NH_2{\cdot}CH_2{\cdot}CO{\cdot}CH_2{\cdot}CH(NH_2){\cdot}CO_2H,2HCl$ (VI.)

$$(R = C_6H_4{<}^{CO}_{CO}{>}N;\ T = CO_2H{\cdot}C_6H_4{\cdot}CO{\cdot}NH.)$$

αδ-Diphthalimido-γ-valerolactone on hydrolysis with concentrated hydrochloric acid gave an almost quantitative yield of αδ-diamino-γ-valerolactone dihydrochloride, which has been obtained by other workers only in small yields (Traube, Johow, and Tepohl, *Ber.*, 1923, **56**, 1861; Tomita, *Z. physiol. Chem.*, 1926, **158**, 58; Hammerstein, *Centr.*, 1916, I, 1811).

EXPERIMENTAL.

Phthalo-ω-iodoacetonylimide (I, X = I).—A mixture of phthalo-ω-chloroacetonylimide (23·5 g.) (Gabriel, *Ber.*, 1917, **50**, 819), sodium iodide (17 g.), and acetone (100 c.c.) was refluxed for 4 hours. *Phthalo-ω-iodoacetonylimide*, which separated on cooling, was washed with water, dilute sulphurous acid, and alcohol and dried; a further quantity was obtained by pouring the mother-liquor into cold water. It crystallised from acetone or alcohol in white needles, m. p. 184°, sparingly soluble in most organic solvents (yield, 80%) (Found: C, 40·0; H, 2·4; I, 38·4. $C_{11}H_8O_3NI$ requires C, 40·1; H, 2·4; I, 38·6%).

Ethyl αδ-Diphthalimido-γ-keto-α-carbethoxyvalerate (II).—Phthalo-ω-iodoacetonylimide (33 g.) was added to a suspension of ethyl sodiophthalimidomalonate in benzene (prepared from ethyl phthalimidomalonate, 35 g., and sodium, 2·3 g.; Sörensen, *Z. physiol. Chem.*, 1905, **44**, 454) containing a few c.c. of alcohol. The mixture was warmed on a water-bath for 4 hours, cooled, and poured into water; the solid that separated was filtered off and repeatedly digested with small quantities of hot alcohol. From the combined alcoholic filtrates, on cooling, long needles of the *ester* (II) separated, m. p. 184° after recrystallisation from alcohol (yield, 3 g.; 7%) (Found: C, 61·4; H, 4·0; N, 5·7. $C_{26}H_{22}O_9N_2$ requires C, 61·7; H, 4·4; N, 5·5%).

αδ-Diamino-γ-ketovaleric Acid Dihydrobromide.—The ester (II) was refluxed with hydrobromic acid (5 parts) for 12 hours, the solution cooled, the phthalic acid removed, the filtrate extracted several times with ether to remove traces of phthalic acid, and the aqueous solution evaporated under reduced pressure. The residue was extracted with small quantities of methyl alcohol; the *dihydrobromide* of αδ-diamino-γ-ketovaleric acid, which remained as a white powder, m. p. 231°, was recrystallised from alcohol (Found: Br, 51·8. $C_5H_{10}O_3N_2,2HBr$ requires Br, 51·9%).

dl-*Thiolhistidine.*—A solution of the above dihydrobromide (3·1 g.) in water (10 c.c.) was warmed on a water-bath, and sodium thiocyanate (1 g.) added during 1 hour. The mixture was heated for another hour, cooled, and a concentrated solution of sodium acetate added. The precipitated *dl*-thiolhistidine was washed and dried; it did not melt even at 320° (Found: C, 38·3; H, 4·7; N, 22·5. Calc. for $C_6H_9O_2N_3S$: C, 38·5; H, 4·8; N, 22·4%). On oxidation with ferric sulphate it gave *dl*-histidine (cf. Pyman, J., 1911, **99**, 681).

δ-Phthalimido-α-carbethoxy-γ-valerolactone (III).—Ethyl malonate (80 g.) and phthalo-βγ-epoxypropylimide (105 g.) were added to a solution of sodium ethoxide (sodium, 11·5 g.; alcohol, 140 c.c.); the mixture was cautiously warmed till the vigorous reaction was over and then boiled for 2½ hours. The alcohol was removed under reduced pressure, and the residue poured into dilute hydrochloric acid and ice. The viscous mass that separated, after solidifying, was washed, dried, and recrystallised from dilute alcohol (norit), giving colourless crystals, m. p. 114° (yield, 60%) (Found: C, 60·4; H, 4·5; N, 4·5. $C_{16}H_{15}O_6N$ requires C, 60·6; H, 4·7; N, 4·4%).

α-Bromo-δ-phthalimido-α-carbethoxy-γ-valerolactone.—A solution of the above ester (31·7 g.) in chloroform (150 c.c.) was mixed with bromine (16·6 g.) and exposed to sunlight (5—6 hours in bright sunlight; 1—3 days in dull light). The solution was repeatedly washed with water, decolourised with sulphurous acid, dried, and evaporated. The viscous residue solidified in contact with water and had m. p. 122° after crystallisation from alcohol. For analysis it was dissolved in the minimum quantity of ether, precipitated with an excess of light petroleum,

and dried in a vacuum desiccator for several days (yield, theoretical) (Found: Br, 19·8. $C_{16}H_{14}O_6NBr$ requires Br, 20·2%).

α-Bromo-δ-phthalimido-α-carboxy-γ-valerolactone.—The above bromo-ester (10 g.), when shaken with hydrobromic acid (*d* 1·78; 50 c.c.) in a strong glass-stoppered bottle for 48 hours, gradually dissolved and granular crystals of the corresponding lactonic acid separated. The mixture was warmed at 50—60° in an open flask for 1 hour to remove ethyl bromide and the excess of hydrobromic acid; it was then cooled, mixed with an equal volume of cold water, and cooled with ice; *α-bromo-δ-phthalimido-α-carboxy-γ-valerolactone* separated in almost colourless crystals (7·2 g.), m. p. 132° (Found: C, 45·4; H, 2·7; N, 3·9; Br, 21·5. $C_{14}H_{10}O_6NBr$ requires C, 45·7; H, 2·7; N, 3·8; Br, 21·7%).

α-Bromo-δ-phthalimido-γ-valerolactone (IV).—The above lactonic acid (50 g.) was heated at 140—150° under reduced pressure until the evolution of carbon dioxide ceased. The oily residue separated from alcohol (charcoal) in colourless crystals, m. p. 140°, which were recrystallised from alcohol (yield, 70%) (Found: C, 48·0; H, 3·1; N, 4·4; Br, 24·6. $C_{13}H_{10}O_4NBr$ requires C, 48·2; H, 3·1; N, 4·3; Br, 24·7%).

αδ-Diphthalimido-γ-valerolactone.—A solution of the bromo-lactone (32·4 g.) in xylene (30 c.c.) was heated at 110°, and potassiophthalimide (18·5 g.) added during 1 hour. After a further 3 hours' heating, the xylene was steam-distilled, and the residual solid washed with water and crystallised from acetic acid; m. p. 260° (yield, theoretical) (Found: C, 64·4; H, 3·3; N, 7·0. $C_{21}H_{14}O_6N_2$ requires C, 64·6; H, 3·6; N, 7·2%).

αδ-Diaminovalerolactone Dihydrochloride.—The preceding lactone (3 g.) was refluxed with hydrochloric acid (40 c.c.) for 24 hours, the mixture cooled, and the phthalic acid removed; the filtrate was concentrated somewhat, shaken with ether to remove traces of phthalic acid, and evaporated to dryness. The residual αδ-diamino-γ-valerolactone dihydrochloride, crystallised from a little water or, better, from dilute alcohol, had m. p. 240° (Found: C, 27·6; H, 6·0; N, 12·6; Cl, 32·1. Calc. for $C_5H_{10}O_2N_2,2HCl,H_2O$: C, 27·7; H, 6·4; N, 12·9; Cl, 32·1%). With potassium cyanate it gave the diureide, m. p. 206°, described by Traube, Johow, and Tepohl (*loc. cit.*).

The dihydrochloride was also obtained by heating the bromo-lactone (IV) with 25% aqueous ammonia (5 parts), evaporating the liquid under reduced pressure, and hydrolysing the residual solid with hydrochloric acid; the solution was cooled, filtered, and evaporated to dryness, and the residue triturated with small quantities of cold water and recrystallised from dilute alcohol.

αδ-Diamino-γ-ketovaleric Acid Dihydrochloride (VI).—αδ-Diphthalimidovalerolactone (20 g.) was warmed with aqueous potassium hydroxide (10 g. in 30 c.c.), the solution cooled, 1% potassium permanganate solution (50 c.c.) added, and the mixture left in ice for a few hours; the manganese dioxide was then removed, and the filtrate strongly acidified. The oily precipitate obtained slowly solidified to a hard resin. This, having been washed, dried, and powdered, was heated at 180° for ½ hour, cooled, and treated with dilute sodium carbonate solution. The residue of αδ-diphthalimidovalerolactone was recrystallised from acetic acid and identified by mixed m. p. The alkaline filtrate on acidification gave a bulky amorphous precipitate. This was washed and then refluxed with hydrochloric acid (20%; 100 c.c.) for 5 hours. The phthalic acid which separated on cooling was removed, and the filtrate extracted with ether and evaporated to dryness at 40—60° under reduced pressure. The mixture of the hydrochlorides of aminoacetic acid and αδ-diamino-γ-ketovaleric acid thus obtained was thrice triturated with concentrated hydrochloric acid (5 c.c.) and the combined filtrates were evaporated under reduced pressure. The residue, consisting mainly of αδ-diamino-γ-ketovaleric acid dihydrochloride, was a syrupy liquid which when left over caustic potash in a vacuum desiccator gave the monohydrochloride described by Harington and Overhoff (*Biochem. J.*, **1933**, **27**, 338). This was dissolved in the minimum quantity of alcohol and reprecipitated with excess of ether. The hydrochloride was converted into *dl*-thiolhistidine by condensing it with sodium thiocyanate.

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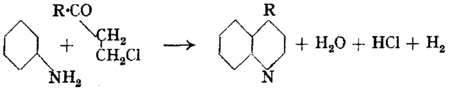
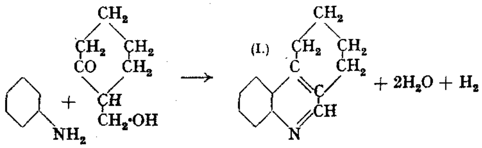
246. *A Synthesis of 5 : 6 : 7 : 8-Tetrahydrophenanthridine and its Derivatives.*

By J. KENNER, W. H. RITCHIE, and F. S. STATHAM.

THE phenanthridine ring system has hitherto received relatively slight attention in comparison with those of the quinoline and *iso*quinoline systems; yet it would be expected, like these, to be represented among natural products, and its presence has in recent years been detected in chelidonine and related alkaloids (v. Bruchhausen and Bersch, *Ber.*, 1930, **63**, 2520; Späth and Kuffner, *ibid.*, 1931, **64**, 370, 1125), tazettin (Späth and Kahovec, *ibid.*, 1934, **67**, 1501), and lycorin (Kondo and Uyeo, *ibid.*, 1935, **68**, 1756). The methods of synthesis at present available are essentially due to Pictet. On the one hand he applied pyrogenetic methods to benzylideneaniline and its derivatives (Pictet and Ankersmit, *Ber.*, 1889, **22**, 3339; *Annalen*, 1891, **266**, 138; Pictet and Erlich, *ibid.*, p. 157; also Etard, *Compt. rend.*, 1882, **95**, 730), and to methylcarbazole (*Ber.*, 1905, **38**, 1950). The unreliability of this in any case unattractive method was shown by Graebe (*Annalen*, 1904, **335**, 122), who found that Pictet's products from benzylidene-α- and -β-naphthylamines were in reality acridine derivatives. A more reliable procedure involves the internal condensation of 2-aminodiphenyl-2′-carboxylic acid (Pictet and Ankersmit, *loc. cit.*; Graebe and Wander, *Annalen*, 1893, **276**, 250; Graebe, *loc. cit.*) or 2-acylaminodiphenyls (Pictet and Hubert, *Ber.*, 1896, **29**, 1183). Although the last method has been recently improved, and applied to a number of cases by Morgan and Walls (J., 1931, 2447; 1932, 2225; 1934, 104), and its range has been enhanced by the development in recent years of the range of available diphenyl derivatives, the ideally flexible synthesis is still one in which the ring system is built up from separate benzene nuclei or their equivalents. Kondo and Uyeo (*loc. cit.*; *Ber.*, 1937, **70**, 1087, 1094) have achieved this by heating a mixture of an *o*-bromobenzaldehyde and an *o*-bromoaniline with copper powder at 200°. We have now been able to extend the synthesis of 4-alkyl- and 4-aryl-quinolines from aromatic amines and β-chloroethyl ketones (Kenner and Statham, *Ber.*, 1936, **69**, 16):

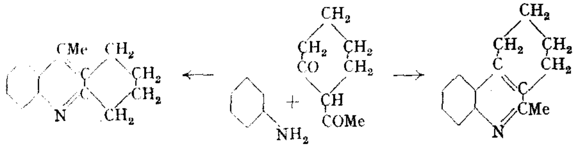


It seemed likely that a β-hydroxyethyl ketone might also be suitable for the purpose as well as being more accessible. Hence 2-hydroxymethyl*cyclo*hexan-1-one (Mannich and Brose, *Ber.*, 1923, **56**, 841) was treated with aniline and aniline hydrochloride in presence of stannic chloride under the conditions previously applied to the chloro-ketones:



5 : 6 : 7-8-*Tetrahydrophenanthridine* (I) was readily isolated from the products, and its identity established by its dehydrogenation with selenium or zinc dust to phenanthridine itself, identical with a specimen prepared by Pictet's process from benzylideneaniline. Further, since Borsche had shown that in certain instances tetrahydroacridines, as well as tetrahydrophenanthridines, may result from the condensation of aromatic amines with 2-acyl*cyclo*hexanones (*Ber.*, 1908, **41**, 2203; *Annalen*, 1910, **377**, 106), the difference

of the new base from tetrahydroacridine was established by direct comparison of the two:



Systematic study showed the new reaction to be applicable with varying yields to alkyl-, halogenated, and alkoxy-derivatives of aniline, although halogen and alkoxy-substituents did not survive the dehydrogenation process. α-Naphthylamine also furnished a phenanthridine, corresponding in its properties with the compound described by Graebe (*loc. cit.*). From β-naphthylamine, however, two isomeric tetrahydro-bases and two dehydrogenated derivatives were obtained. A detailed account of this work is deferred until it can more suitably be presented in relation to the results of the condensation of ethyl β-aminocrotonate with the methylol derivative.

Although the use of stannic chloride determined the practical success of the synthesis of 4-alkylquinolines, and it was consequently employed in the above instances, further experiments by Dr. R. L. Wain have shown it to be unnecessary. As a further simplification the methylol can be used with equal success in the form of the solution resulting from the interaction of aqueous formaldehyde solution and *cyclo*hexanone. As the latter can be carried out on a large scale, there is an economy of time and labour which to some extent compensates the moderate yields.

Experimental.

2-Hydroxymethyl*cyclo*hexan-1-one was prepared essentially according to the directions of Mannich and Brose (*loc. cit.*) by addition of lime (6·4 g.) during 30 minutes to a well-stirred mixture of *cyclo*hexanone (1720 c.c.), 40% formaldehyde solution (1065 c.c.), and water (160 c.c.). When the initial temperature was 19°, the rate of reaction soon accelerated and in order to prevent a temperature of 38° from being exceeded it was necessary to apply vigorous cooling, first by water and then by ice, when the mixture was at 28—30°. As soon as the temperature had begun to fall after reaching its maximum, the cooling medium was withdrawn, and subsequent procedure followed that of the above authors. 2-Hydroxymethyl-4-methyl*cyclo*hexanone resulted similarly from a mixture of 4-methyl*cyclo*hexanone (56 g.), 40% formaldehyde solution (70 g.), alcohol, and 0·8% sodium hydroxide solution (100 c.c.). After about 45 minutes the rise in temperature of the light brown mixture was restrained by water-cooling, and the mixture subsequently stirred at the ordinary temperature for 5 hours. The methylol (9 g.), b. p. 138—145°/40 mm., isolated as in the previous case, furnished a p-*nitrophenylhydrazone*, orange-yellow needles, m. p. 144—145° (Found: N, 14·8. $C_{14}H_{19}O_3N_3$ requires N, 15·2%). Attempts to prepare similar derivatives of 2-methyl*cyclo*hexanone and *cyclo*pentanone were unsuccessful.

Condensation of Formaldehyde with α-Tetralone.—A mixture of α-tetralone (58·4 g.), 40% formaldehyde solution (30 g.), alcohol (130 c.c.), and water (70 c.c.) was treated with 40% sodium hydroxide solution (0·5 c.c.). After ½ hour, when the temperature had risen 10°, the purple-red mixture was cooled and left for 2½ hours. The product, separated as before, yielded 25 g., b. p. up to 90° and chiefly 84—86°/0·2—0·3 mm., and 15·5 g., b. p. 100—127°/0·2—0·4 mm. The latter fraction gradually solidified and yielded plates, m. p. 106—107°, after recrystallisation from alcohol. The compound decolorised bromine and its analysis indicated that it was 2-*methylene-α-tetralone* (Found: C, 83·2; H, 6·5. $C_{11}H_{10}O$ requires C, 83·5; H, 6·3%).

5 : 6 : 7 : 8-*Tetrahydrophenanthridine.*—(a) A mixture of 2-hydroxymethyl*cyclo*hexanone (12·8 g.), aniline (18·6 g.), aniline hydrochloride (18·6 g.), stannic chloride hydrate (40·6 g.), and alcohol (20 c.c.) was heated at 100° for 7 hours. On fractional distillation of the basic products, the portion, b. p. 100—230°/20 mm., yielded a yellow *picrate* (7·8 g.), m. p. 210—212° after crystallisation from alcohol (Found: C, 55·3; H, 4·2; N, 13·7. $C_{13}H_{13}N,C_6H_3O_7N_3$ requires C, 55·3; H, 3·9; N, 13·6%). The free *base*, liberated from the picrate, separated from light petroleum (b. p. 40—60°) in plates, m. p. 64° (Found: C, 85·0; H, 7·1; N, 7·7. $C_{13}H_{13}N$ requires C, 85·2; H, 7·1; N, 7·6%). In contrast with phenanthridine, it showed no fluorescence

in concentrated sulphuric acid solution. A mixture of the base with authentic tetrahydroacridine (m. p. 54°; Borsche, *loc. cit.*) was liquid at the ordinary temperature. Alternatively the base was isolated by treating the basic fraction, b. p. 90—340°/17 mm., with an equal volume of acetic anhydride at 100° for 1 hour. From the product an *acetyl* derivative was separated, m. p. 228·5—230°, and after successive crystallisation from dilute alcohol, methyl alcohol (twice), and water was obtained as needles (Found : N, 10·1%). This was not further investigated.

(b) The same yield of picrate was obtained from a repetition of the above experiment in which stannic chloride was omitted and the amount of aniline was halved.

(c) Comparative experiments having shown that the crude reaction mixture from the condensation of formaldehyde with *cyclo*hexanone could be used under the conditions just indicated on the basis of a 70% conversion into hydroxymethyl derivative, the reaction mixture from 100 g. of *cyclo*hexanone was, immediately after neutralisation with acetic acid, treated with aniline (65 g.), aniline hydrochloride (91 g.), and alcohol (50 c.c.) as in (a). The basic fraction (98 g.), b. p. 100—250°/33 mm., yielded 57 g. of nearly pure picrate.

Phenanthridine resulted when the tetrahydro-derivative (1·8 g.) was heated at 270—280° for ½ hour with selenium powder (1·5 g.), and then for a further 12 hours at 320°. The basic product, separated by direct distillation, was purified through its picrate (1·6 g.), m. p. 247—248° after crystallisation from alcohol (Found : C, 55·6; H, 3·0; N, 13·7. Calc. for $C_{13}H_9N,C_6H_3O_7N_3$: C, 55·9; H, 2·9; N, 13·7%). The free base separated from ligroin in plates, m. p. 107° (Found : C, 86·9; H, 5·2; N, 7·9%), and did not depress the m. p. of a sample prepared from benzylideneaniline. Its *platinichloride* shrank at 217° and melted at 219—221° (decomp.) [Found : Pt, 24·7. $(C_{13}H_9N)_2,H_2PtCl_6$ requires Pt, 25·3%].

In the preparation of the following compounds the above procedure (a) was followed, the acetylation method being employed for the preliminary purification of the tetrahydrophenanthridine. Doubtless the yields indicated would also be attained without the use of stannic chloride.

3-*Methyl*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from *p*-toluidine (27% yield), had m. p. 231—232° (decomp.) (Found : N, 13·0. $C_{14}H_{15}N,C_6H_3O_7N_3$ requires N, 13·1%). The free *base* crystallised from ligroin in plates, m. p. 73·5° (Found : C, 85·1; H, 7·8; N, 7·2. $C_{14}H_{15}N$ requires C, 85·3; H, 7·6; N, 7·1%). 3-Methylphenanthridine separated from ligroin in pale yellow needles, m. p. 89° (Found : C, 86·7; H, 5·9; N, 7·6. Calc. for $C_{14}H_{11}N$: C, 87·0; H, 5·7; N, 7·3%), and yielded a yellow picrate, m. p. 266° (decomp.) (Found : N, 13·2. Calc. for $C_{14}H_{11}N,C_6H_3O_7N_3$ requires N, 13·3%). Pictet and his collaborators (*loc. cit.*) give 131° and 202° as m. p.'s of the base and its picrate respectively. In a repetition of their experiment a picrate was obtained which melted at 245—250° (decomp.) after several recrystallisations, and its mixture with the picrate, m. p. 266°, melted at 255—260°. 1-*Methyl*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from *o*-toluidine (21% yield), had m. p. 203—204° (decomp.) (Found : N, 13·2. $C_{14}H_{15}N,C_6H_3O_7N_3$ requires N, 13·1%); the free *base* formed plates, m. p. 80·5° (Found : C, 85·2; H, 7·7; N, 7·0. $C_{14}H_{15}N$ requires C, 85·3; H, 7·6; N, 7·1%). 1-Methylphenanthridine had m. p. 95·5° (Found : C, 87·0; H, 5·8; N, 7·6. Calc. for $C_{14}H_{11}N$: C, 87·0; H, 5·7; N, 7·3%), and its picrate, m. p. 234° (decomp.) (Found : N, 13·4. Calc. for $C_{14}H_{11}N,C_6H_3O_7N_3$: N, 13·3%). Pictet and his collaborators (*loc. cit.*) give 70° and 220° as m. p.'s of the base and its picrate respectively.

1 : 3-*Dimethyl*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from *m*-xylidine (23% yield), had m. p. 212·5° (decomp.) (Found : N, 12·8. $C_{15}H_{17}N,C_6H_3O_7N_3$ requires N, 12·7%). The free *base* had m. p. 49·5—50·5° (Found : C, 85·2; H, 8·0. $C_{15}H_{17}N$ requires C, 85·3; H, 8·1%).

1 : 3-*Dimethylphenanthridine*, m. p. 84·5° (Found : C, 86·8; H, 6·3; N, 6·8. $C_{15}H_{13}N$ requires C, 87·0; H, 6·3; N, 6·8%), furnished a *picrate*, m. p. 261° (decomp.) (Found : N, 12·9. $C_{15}H_{13}N,C_6H_3O_7N_3$ requires N, 12·8%). It exhibited a weaker blue fluorescence than phenanthridine in concentrated sulphuric acid.

1 : 4-*Dimethyl*-5 : 6 : 7 : 8-*tetrahydrophenanthridine*, from *p*-xylidine (b. p. 221—223° after purification by crystallisation of its hydrochloride, m. p. 211°, from dilute hydrochloric acid; acetyl derivative, m. p. 144—145°; benzoyl derivative, m. p. 153°), was obtained in the crude state, b. p. 90—250° (mainly 210—215°)/25 mm. (15% yield), and finally purified by repeated crystallisation from light petroleum (b. p. below 40°); it formed long needles, m. p. 63—63·5° (yield, 6·5%) (Found : C, 84·9; H, 8·1; N, 6·9. $C_{15}H_{17}N$ requires C, 85·3; H, 8·1; N, 6·6%); the *picrate* had m. p. 180—181° (decomp.) (Found : N, 12·9. $C_{15}H_{17}N,C_6H_3O_7N_3$ requires N, 12·7%).

1 : 4-*Dimethylphenanthridine* formed pale yellow clusters of needles, m. p. 76·5°, which showed

no fluorescence in concentrated sulphuric acid solution (Found: C, 86·8; H, 6·4; N, 6·9. $C_{15}H_{13}N$ requires C, 87·0; H, 6·3; N, 6·8%); the *picrate* had m. p. 222° (Found: N, 12·8. $C_{15}H_{13}N,C_6H_3O_7N_3$ requires N, 12·8%).

3-*Bromo*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from *p*-bromoaniline (23·5% yield), had m. p. 221—222° (decomp.) (Found: N, 11·6. $C_{13}H_{12}NBr,C_6H_3O_7N_3$ requires N, 11·4%). The free *base* had m. p. 110° (Found: C, 59·5; H, 4·8; N, 5·6. $C_{13}H_{12}NBr$ requires C, 59·5; H, 4·6; N, 5·4%).

3-*Chloro*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from *p*-chloroaniline (26% yield), had m. p. 214° (decomp.) (Found: N, 12·6. $C_{13}H_{12}NCl,C_6H_3O_7N_3$ requires N, 12·5%). The free *base* had m. p. 90° (Found: C, 71·6; H, 5·6; N, 6·6. $C_{13}H_{12}NCl$ requires C, 71·7; H, 5·5; N, 6·4%).

1-*Nitro*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, obtained from *o*-nitroaniline in very poor yield, had m. p. 216—217° (decomp.) (Found: N, 14·9. $C_{13}H_{12}N_2O_2,C_6H_3O_7N_3$ requires N, 15·3%), and yielded an oily base.

3-*Methoxy*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from *p*-anisidine (34% yield), had m. p. 241—242° (decomp.) (Found: N, 12·8. $C_{14}H_{15}ON,C_6H_3O_7N_3$ requires N, 12·7%). The free *base* had m. p. 110—111° (Found: C, 78·7; H, 7·1; N, 6·8. $C_{14}H_{15}ON$ requires C, 78·8; H, 7·0; N, 6·6%).

1 : 4-Dimethoxy-5 : 6 : 7 : 8-tetrahydrophenanthridine picrate, from 2 : 5-dimethoxyaniline, had m. p. 194—195° (decomp.) (yield, 5·3%). The free *base* had m. p. 86·5—87° (Found: C, 73·9; H, 7·1; N, 6·1. $C_{15}H_{17}O_2N$ requires C, 74·1; H, 7·0; N, 5·8%).

7-*Methyl*-5 : 6 : 7 : 8-*tetrahydrophenanthridine picrate*, from 2-hydroxymethyl-4-methyl*cyclo*-hexanone and aniline, had m. p. 195—196° (decomp.) (yield, 21%) (Found: N, 13·4. $C_{14}H_{15}N,C_6H_3O_7N_3$ requires N, 13·1%). The free *base* had m. p. 45° (Found: C, 84·9; H, 7·7; N, 7·3. $C_{14}H_{15}N$ requires C, 85·3; H, 7·6; N, 7·1%). 7-*Methylphenanthridine*, m. p. 88° (Found: C, 86·9; H, 5·8; N, 7·4. $C_{14}H_{11}N$ requires C, 87·0; H, 5·7; N, 7·2%), formed a *picrate*, m. p. 236—237° (decomp.) (Found: N, 13·3. $C_{14}H_{11}N,C_6H_3O_7N_3$ requires N, 13·3%).

Tetrahydro-α-naphthaphenanthridine picrate, from α-naphthylamine, had m. p. 215—216° (decomp.) (yield, 15%) (Found: N, 12·1. $C_{17}H_{15}N,C_6H_3O_7N_3$ requires N, 12·1%). The free *base* had m. p. 118° (Found: C, 87·2; H, 6·6; N, 6·2. $C_{17}H_{15}N$ requires C, 87·5; H, 6·4; N, 6·0%). α-Naphthaphenanthridine, m. p. 135° (Found: C, 88·8; H, 4·9; N, 6·1. Calc. for $C_{17}H_{11}N$: C, 89·1; H, 4·8; N, 6·1%), formed a picrate, m. p. 255° (decomp.) (Found: N, 12·1. Calc. for $C_{17}H_{11}N,C_6H_3O_7N_3$: N, 12·2%). Graebe (*loc. cit.*) records m.p.'s 135·5° and 256° for the base and its picrate respectively.

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247. *The Chemical Kinetics of the Interaction of the Alkyl Iodides with Sodium Eugenoxide in Ethyl Alcohol.*

By Sidney S. Woolf.

The kinetics of the reactions of alkyl iodides with various reagents, in particular the phenoxides, have been extensively studied. In early researches the observation that the bimolecular velocity constants in these reactions varied with initial concentrations was dealt with on empirical lines. The introduction of the "dual catalysis" hypothesis, however, led to an explanation of the reaction mechanism on the basis that ions and undissociated molecules of the phenoxide both played their part. By Acree's equation, viz., $k_{obs.} = k_i\alpha + k_m(1 - \alpha)$, it is possible to split the observed velocity constant into separate constants for ions and molecules (k_i and k_m respectively), α being the apparent degree of dissociation, and k_i and k_m being independent of the dilution. Recent extensions of kinetic theory have made it possible to classify the alkyl iodide–phenoxide reactions as "normal," *i.e.*, substantially free from factors reducing the perfect efficiency of activating collisions.

In the present work, the phenol studied was eugenol, and the rates of reaction in ethyl alcoholic solution of sodium eugenoxide with eight alkyl iodides in equivalent proportion were observed over as large a range of temperature and initial concentration as practicable. The bimolecular nature of the reactions was established, and the heats of activation and relative reactivities of the alkyl iodides in the individual reactions were ascertained.

The measured velocities depend almost entirely on the interaction of the alkyl iodide with eugenoxide ions, the values of k_m derived from the Acree equation being negligible.

A preliminary study was also made of the behaviour of the reactants when originally present in non-equivalent proportions; also, to investigate the unexplained fall in constant usually noticed in such reactions, some experiments were carried out in which resultants were added to the original equivalent reaction mixtures.

EXPERIMENTAL.

Preparation of Materials.—The alkyl iodides (methyl, ethyl, *n*- and *iso*-propyl, *n*- and *iso*-butyl, and *n*- and *iso*-amyl) as supplied by Messrs. British Drug Houses nearly always contained free iodine. They were washed with dilute alkali solution and water, dried over anhydrous calcium chloride, fractionally distilled, and stored over freshly ignited silver powder. In no case was there any sign of subsequent discoloration, although some specimens were kept for several years.

Commercial absolute alcohol was refluxed on a water-bath for 20—30 hours with freshly-burnt lime, and was fractionated, giving alcohol of a satisfactory quality, as established by conductivity measurements.

Eugenol (B.D.H.) was fractionated, the fraction of b. p. 249—251° being retained. It was stored in glass-stoppered amber-glass bottles, and each batch remained colourless over its period of use (less than 3 months).

Alcoholic sodium ethoxide solutions, prepared by dissolving clean sodium in absolute alcohol, were standardised by titration with standard hydrochloric acid, litmus being used as indicator. Sodium eugenoxide solutions were prepared by mixing eugenol with the calculated volume of alcoholic sodium ethoxide. A 10% excess over the stoicheiometric quantity of eugenol was used throughout in order to inhibit alcoholysis.

Course of the Reaction.—It was shown by quantitative isolation and identification of ethers that the reactions are represented by the equation

$$RI + ONa{\cdot}C_6H_3(OMe){\cdot}CH_2{\cdot}CH{:}CH_2 \longrightarrow NaI + OR{\cdot}C_6H_3(OMe){\cdot}CH_2{\cdot}CH{:}CH_2.$$

The methyl ether of eugenol (b. p. 248—250°) was prepared from methyl iodide and sodium eugenoxide; and its bromination produced 4-bromo-5-βγ-dibromopropylveratrole (m. p. 78·5—79°) (cf. *Ber.*, 1895, **28**, 2082). The ethyl ether was obtained in 93% yield from the reaction of ethyl iodide with sodium eugenoxide.

Measurement of Reaction Velocity.—Equivalent solutions of the reactants were mixed, and 10 ml. quantities were pipetted into hard-glass test-tubes which were closed with rubber bungs and transferred to a thermostat bath, controlled to ± 0·05°. On attaining constant temperature (10 mins.), a tube was withdrawn, emptied into cold water, and the unchanged sodium eugenoxide titrated with standard hydrochloric acid, litmus being the indicator. Similar measurements were made at suitable intervals until " half-reaction " was reached.

The bimolecular equation $k = (1/t) \cdot (1/C_t - 1/C_0)$ was applied, concentrations being expressed in g.-mols./l., and time in minutes, but as values of k so obtained decreased during an experiment (mainly owing to accumulation of resultants), a graphical method was adopted in order to determine velocity constants at zero time. All observed values of $1/C$ were plotted against t, and the best straight line drawn through these points, and extrapolated back to the value of $1/C$ at zero reaction ($1/C_0$). The corresponding time t_0 was taken as the " hypothetical time-zero," and this appears in Table I as a number of minutes prior to the arbitrarily chosen time-zero used in the experiment. The fall in constant is thus eliminated.

All results were corrected for expansion, the coefficient of expansion of ethyl alcohol being used.

Values of k were obtained for each of the eight alkyl iodides at three different temperatures, and at initial dilutions extending over the range $V = 4$ to $V = 20$ l./g.-mol.

The results of a typical experiment are given in full (Table I), and values for the remainder are summarised in Table II, the progressive increase in k with initial dilution being evident.

In order to correlate the results obtained at different temperatures and dilutions, it was desirable to deduce the values of velocity constants at common " round-number " dilutions. Over the range studied it was found that k varied linearly with V, and this observation was used to obtain values of k at $V = 4$, 6, 8, 10, 12, 14, and 16 l./g.-mol. for each iodide at the working temperatures.

TABLE I.

Methyl iodide at 42·5°.

Concn. of each reactant before mixing at 15° = N/4. Dilution (V) of each reactant in mixture at 42·5° = 8·23. Acid = 0·0505N-HCl. Hypothetical zero time = −21 mins.

t	0	5	10	15	20	30	45	70	
Titre (ml.)	20·2	19·2	18·4	17·7	17·0	15·9	14·3	12·5	
$k \times 10^4$	856	884	887	883	888	873	883	862	Mean 877

Temp. correction factor: 1·0287; k (corr. for temperature) = 903 × 10^{-4}.

TABLE II.

C_0' = Concentration of each reactant before mixing.

C_0'.	100k.	C_0'.	100k.	C_0'.	100k.	C_0'.	100k.	C_0'.	100k.	C_0'.	100k.
		Methyl iodide.						*Ethyl iodide.*			
42·5°.		50°.		55°.		50°.		57·5°.		68°.	
N/2	7·41	3N/8	15·14	N/2	21·8	N/2	3·56	N/2	7·02	N/4	20·9
N/4	9·03	N/4	17·10	3N/8	22·5	N/4	4·78	3N/8	7·39	3N/16	23·3
3N/16	9·86	3N/16	19·59	N/4	27·3	3N/16	5·29	N/4	8·72	N/8	29·8
N/8	12·66	N/8	24·25	3N/16	30·1	N/8	6·56	3N/16	9·35		
		N/10	31·52	N/8	36·9			N/8	12·43		
		n-*Propyl iodide.*						n-*Butyl iodide.*			
57·5°.		68°.		75°.		57·5°.		68°.		75°.	
N/2	2·55	N/2	6·71	3N/8	13·28	N/2	2·38	N/2	5·93	N/2	10·63
3N/8	2·84	3N/8	7·30	N/4	15·09	3N/8	2·59	N/4	7·70	N/4	13·49
5N/16	2·97	N/4	8·40	3N/16	17·10	N/4	3·01	N/8	11·40	3N/16	15·62
N/4	3·16	3N/16	9·83	N/8	21·04			N/10	13·19	N/8	19·34
		N/8	12·46	N/10	24·12					N/10	21·46
		n-*Amyl iodide.*						iso*Propyl iodide.*			
57·5°.		68°.		75°.		57·5°.		68°.		75°.	
N/2	2·26	3N/8	6·06	N/2	10·13	N/2	1·83	N/2	4·96	N/2	9·23
3N/8	2·49	N/4	7·07	N/4	12·54	3N/8	2·04	N/4	6·34	N/4	11·48
N/4	2·88	3N/16	8·20	3N/16	14·03	N/4	2·45	3N/16	7·33	3N/16	12·96
		N/8	10·02	N/8	17·42			N/8	9·35	N/8	16·68
				N/10	19·97					N/10	18·91
		iso*Butyl iodide.*						iso*Amyl iodide.*			
57·5°.		68°.		75°.		57·5°.		68°.		75°.	
N/2	0·86	N/2	2·23	N/2	3·27	N/2	1·31	N/2	2·91	N/2	4·99
3N/8	0·96	3N/8	2·52	N/4	4·47	3N/8	1·46	3N/8	3·20	N/4	6·83
N/4	1·12	N/4	2·68	3N/16	5·52	N/4	1·69	N/4	4·08	3N/16	8·11
		3N/16	3·26	N/8	7·59			3N/16	4·90	N/8	11·05
		N/8	4·37	N/10	9·84			N/8	6·80	N/10	12·75

Determination of the Apparent Degree of Dissociation of Sodium Eugenoxide in Absolute Alcohol.—Conductivity measurements were made at 25°, 35°, and 50°, solutions being prepared by successive dilutions of a 0·25N-solution of sodium eugenoxide in alcohol with a 0·05N-solution of eugenol in alcohol (to counteract alcoholysis). The results are summarised in Table III, where κ is the specific conductivity of the solvent in reciprocal ohms and μ_v the corresponding molecular conductivity, the value at infinite dilution μ_∞ being obtained by extrapolation of the most dilute readings when μ_v was plotted against $\sqrt{1/v}$.

TABLE III.

V.	4.	8.	16.	32.	64.	128.	256.	512.	1024.	2048.	∞.
					Temp. 25°; $\kappa = 0·93 \times 10^{-6}$.						
μ_v	2·707	3·854	5·303	7·129	9·479	12·31	15·74	19·72	24·27	27·65	36
					Temp. 35°; $\kappa = 1·0 \times 10^{-6}$.						
μ_v	2·861	4·019	5·492	7·326	9·863	12·77	16·47	20·91	25·95	30·45	41
					Temp. 50°; $\kappa = 1·1 \times 10^{-6}$.						
μ_v	3·417	4·705	6·362	8·589	11·42	14·99	19·68	25·45	31·96	38·09	51

From the molecular conductivities at 25°, 35°, and 50° so obtained, those for $V = 4, 8, 16$, and ∞ at the various temperatures ranging from 42·5° to 75° were calculated from the expression $\mu_t = \mu_0(1 + \beta t)$. Then, from $\alpha = \mu_v/\mu_\infty$, values for α were obtained. As a check on this, values of α at 25°, 35°, and 50° were calculated from the actual values of μ observed, and extrapolated mathematically to the working temperatures by the empirical relationship $\alpha_t = \alpha_0(1 - \gamma t)$. The means of the satisfactorily concordant values of α obtained by these two methods were used in subsequent calculations.

The values of α obtained gave approximate concordance with Ostwald's dilution law over the range studied, and were accordingly plotted against $\sqrt{v}$ in order to obtain α for the intermediate dilutions ($V = 6, 10, 12$, and 14). In Table IV values of α at "round number" dilutions and at the working temperatures are summarised.

TABLE IV.

V.	42·5°.	50°.	55°.	57·5°.	68°.	75°.	V.	42·5°.	50°.	55°.	57·5°.	68°.	75°.
4	0·069	0·066	0·065	0·064	0·062	0·060	12	0·114	0·109	0·105	0·103	0·097	0·093
6	0·083	0·079	0·077	0·076	0·073	0·070	14	0·122	0·117	0·113	0·111	0·104	0·100
8	0·095	0·091	0·088	0·087	0·082	0·079	16	0·130	0·124	0·120	0·118	0·110	0·106
10	0·105	0·100	0·097	0·095	0·090	0·086							

DISCUSSION OF RESULTS.

Application of Theory of Dual Catalysis.—When the values of k at the various temperatures and dilutions were plotted against the corresponding values of α, a series of straight lines was obtained for each iodide, all of which passed through the origin within experimental error, *i.e.*, as mentioned above, k_m is negligible, and the slope of the lines $(k_i - k_m)$ reduces to k_i. Acree's equation therefore becomes $k = k_i\alpha$, and k_i ($= k/\alpha$) is the characteristic velocity constant for a given iodide and temperature, the dilution factor having thus been eliminated. This is confirmed by substituting the values of k and α for a given iodide and temperature in the original Acree equation, and solving the pairs of simultaneous equations for each dilution for k_i and k_m; *e.g.*, for *n*-propyl iodide at 75°, the mean values of k_i and k_m are 1·90 and −0·001 respectively, whilst the mean of the corresponding values of k/α ($= k_i$) is 1·91.

In Table V are summarised, for experiments carried out at 75°, the interpolated values of k at "round-number" dilutions, and the values of k_i obtained by dividing these by the appropriate values of α (Table IV), and Table VI summarises the mean values of k_i obtained in this way, for all iodides and temperatures.

TABLE V.

	$V=$	4.	6.	8.	10.	12.	14.	16.	Mean k_i.
n-Propyl iodide	$100k$	11·9	13·4	14·8	16·2	17·6	19·0	20·4	
	k_i	1·98	1·91	1·87	1·88	1·89	1·90	1·92	1·91
n-Butyl iodide	$100k$	10·4	11·8	13·1	14·4	15·8	17·1	18·4	
	k_i	1·73	1·69	1·66	1·68	1·70	1·71	1·73	1·70
n-Amyl iodide	$100k$	9·8	11·0	12·2	13·4	14·6	15·7	16·8	
	k_i	1·63	1·57	1·54	1·56	1·57	1·57	1·58	1·57
*iso*Propyl iodide	$100k$	9·0	10·1	11·2	12·4	13·6	14·7	15·8	
	k_i	1·50	1·44	1·42	1·44	1·46	1·47	1·49	1·46
*iso*Butyl iodide	$100k$	3·4	4·0	4·6	5·2	5·8	6·5	7·1	
	k_i	0·57	0·57	0·58	0·60	0·62	0·65	0·67	0·61
*iso*Amyl iodide	$100k$	5·1	6·0	6·8	7·7	8·6	9·4	10·3	
	k_i	0·85	0·85	0·86	0·89	0·92	0·94	0·97	0·90

TABLE VI.

Iodide.	75°.	68°.	57·5°.	55°.	50°.	42·5°.
Methyl	—	—	—	3·00	1·90	0·95
Ethyl	—	2·50	1·00	—	0·52	—
n-Propyl	1·91	1·04	0·38	—	—	—
n-Butyl	1·70	0·94	0·35	—	—	—

Iodide.	75°.	68°.	57·5°.
n-Amyl	1·57	0·87	0·33
*iso*Propyl	1·46	0·78	0·29
*iso*Butyl	0·61	0·34	0·136
*iso*Amyl	0·90	0·51	0·203

Temperature Coefficients, Critical Increments, and Relative Reactivities.—When the observed values of log k_i are plotted against the reciprocal of the absolute temperature, the Arrhenius

straight-line law is obeyed. The corresponding equation $\log k_1 - \log k_2 = A(1/T_2 - 1/T_1)$ was therefore used to obtain values for 50° for those iodides which had not been measured at this temperature, which was adopted because it had been used by former workers and because the extrapolation involved was short. Table VII shows the values (averaged over the temperatures used) of the temperature coefficient (k_{t+10}/k_t), which approximate to the normal value of 2·5. The table also shows the values of E (in kg.-cals./g.-mol.), calculated from $E = 2{\cdot}303AR$, and the relative reactivities (r) of the alkyl iodides at 50° (*n*-propyl iodide = 10·0).

TABLE VII.

Iodide.	Temp. coeff.	*E*.	*r*.	Iodide.	Temp. coeff.	*E*.	*r*.
Methyl	2·51	18·9	104	*n*-Amyl	2·45	20·3	8·9
Ethyl	2·37	19·0	28·6	*iso*Propyl	2·54	21·1	7·5
n-Propyl.........	2·53	21·0	10·0	*iso*Butyl	2·38	19·6	3·7
n-Butyl	2·48	20·6	9·3	*iso*Amyl	2·36	19·4	5·6

The relative reactivities show satisfactory agreement with those recorded by other workers for similar reactions. As usual, methyl iodide is some 10 times and ethyl iodide 2—3 times as reactive as propyl iodide, and with further ascent of the homologous series the reactivity lessens, tending towards a limiting value. The *iso*-iodides are less reactive than the corresponding *n*-iodides, and the anomalous behaviour of *iso*butyl iodide, reported by earlier workers, is again in evidence.

Mechanism of the Reaction from the Aspect of Collision Theory.—In Table VIII, typical values of k_t are compared with values calculated from the modified Lewis equation

$$k = (N/1000)\sigma_{1,2}^2[8\pi RT(1/M_1 + 1/M_2)]^{\frac{1}{2}}.\ e^{-E/RT}$$

where M_1 and M_2 are the molecular weights of the reactants, $\sigma_{1,2}$ is the sum of their molecular radii, N the Avogadro constant, E the " critical increment " in cals./g.-mol., and k the velocity constant in l./g.-mol.-sec.

The ratio $k_{t,\,\text{obs.}}/k_{t,\,\text{calc.}}$ can be identified with P, the probability factor in Hinshelwood's equation $k = PZe^{-E/RT}$, where Z is the collision frequency, and the order of these figures indicates that the interactions under investigation are "normal," a factor of 10 or 0·1 being not unusual in this sense.

TABLE VIII.

Iodide.	Temp.	10^3k_t, calc.	10^3k_t, obs.	*P*.	Iodide.	Temp.	10^3k_t, calc.	10^3k_t, obs.	*P*.
Methyl	50°	22·7	31·7	1·4	*iso*Butyl ...	75°	66·5	10·2	0·2
Ethyl	50	18·8	8·7	0·5	*iso*Butyl ...	50	7·2	1·1	0·2
n-Propyl ...	75	8·9	31·8	3·6	*n*-Amyl	68	12·9	14·5	1·1
n-Propyl ...	50	0·8	3·0	3·7	*iso*Amyl ...	57·5	19·2	3·4	0·2
*iso*Propyl ...	68	4·0	13·0	3·2				Mean	1·6

Non-equivalent Reactions.—The results of a few " non-equivalent " experiments with *n*-propyl iodide are tabulated below, together with corresponding " equivalent " reactions for comparison.

Original concentration of reactant in mixture.			Original concentration of reactant in mixture.		
Sodium eugenoxide.	*n*-Propyl iodide.	10^4k (obs.).	Sodium eugenoxide.	*n*-Propyl iodide.	10^4k (obs.).
$N/4$	$N/4$	671	$3N/16$	$3N/16$	730
$N/4$	$N/8$	757	$N/8$	$N/4$	793
$3N/32$	$3N/32$	983	$N/8$	$N/8$	840
$N/16$	$N/16$	1246	$N/8$	$N/16$	961

The general conclusion that excess or deficiency of " phenoxide " lowers or raises the constant respectively is thus confirmed. The inference that " phenoxide " concentration is the prevailing influence in these " non-equivalent " experiments falls in line with the dual catalysis viewpoint, but the lowering of the constant observed with excess of alkyl iodide in some cases (including the present) is not yet clearly understood.

SUMMARY AND CONCLUSIONS.

(1) The reactions of sodium eugenoxide with eight alkyl iodides in absolute ethyl alcohol have been studied kinetically at various concentrations and temperatures. The fundamental reaction is essentially bimolecular, but of a special type, the constant for a given iodide and temperature increasing with dilution.

(2) The apparent degrees of ionisation of sodium eugenoxide in absolute alcohol were determined from conductivity experiments, and application of the theory of "dual catalysis" to the observed velocity constants shows that the reaction is due almost exclusively to interaction of eugenoxide ions with the alkyl iodides, the reactivity of unionised molecules of sodium eugenoxide being negligible. Characteristic velocity constants for the ionic reactions were obtained, and found to be independent of initial concentration in equivalent reactions.

(3) The temperature coefficient of the reactions was *ca.* 2·5 for 10° rise. The logarithms of the velocity constants varied linearly with the reciprocal of the absolute temperature, and the Arrhenius "critical increments" were calculated to be 19,000—21,000 cals./g.-mol.

(4) The mechanism of the reactions was investigated from the aspect of the modern collision theory as applied to reactions in solution, and they were found to be "normal" in type, the probability factor P in the standard equation $k = PZe^{-E/RT}$ being of the order of unity.

(5) The relative reactivities of the alkyl iodides were closely comparable with earlier values for similar reactions.

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248. *Mechanism of Substitution at a Saturated Carbon Atom. Part VII. Hydrolysis of* iso*Propyl Halides.*

By EDWARD D. HUGHES and URIEL G. SHAPIRO.

The determinations of the rate constants and of B and E in the Arrhenius equation, $k = Be^{-E/RT}$, for the substitution and elimination reactions which have been shown to occur simultaneously in the alkaline hydrolysis of *iso*propyl bromide are here extended to include the chloride and the iodide. The simultaneous reactions are a "bimolecular" substitution, *e.g.*,

$$OH^- + Pr^{\beta}Br \longrightarrow Pr^{\beta}OH + Br^-$$

a "unimolecular" substitution, *e.g.*,

$$\begin{cases} Pr^{\beta}Br \xrightarrow[\text{slow}]{} Pr^{\beta+} + Br^- \\ Pr^{\beta+} + OH^- \xrightarrow[\text{fast}]{} Pr^{\beta}OH \end{cases}$$

and a "bimolecular" elimination, *e.g.*,

$$OH^- + Pr^{\beta}Br \longrightarrow C_3H_6 + H_2O + Br^-$$

For all the reactions there is a much larger velocity difference between chloride and bromide than between bromide and iodide: the observed spacing is referred to a joint dependence of the rate on both C–Hal. bond-strength and halogen polarisability. The bimolecular substitution is much slower for the *iso*propyl than for the ethyl halides in agreement with views advanced in earlier papers. The dependence of the chief velocity differences on the separate parameters of the Arrhenius equation is discussed.

MUCH has been written in previous parts of this series on the interest attaching to such sequences as Alk = Me, Et, Pr^{β}, Bu^{γ} in relation to the mechanism and kinetics of nucleophilic substitutions of the form

$$Y + Alk \vdots\!—X \longrightarrow Y—Alk + X$$

Experimental studies have been contributed for this and other alkyl series in cases in which the substituting agent Y takes forms such as $\bar{O}H$, $\bar{O}Et$, $\bar{O}Ph$, $\bar{O}Ac$, $\bar{Hal}$. whilst the displaced group X is $\overset{+}{N}R_3$, $\overset{+}{S}R_2$ or Hal. This paper continues the study of the homologous alkyl series, and belongs to the group of investigations for which the substituting agent is $\bar{O}H$ or $\bar{O}Et$ and the displaced group a halogen atom.

It has been shown that, for the first two members of the alkyl series, Alk = Me, Et, the substitution of the halogen by OH or OEt is a bimolecular process, whilst for the last member Alk = Bu^{γ} substitution by OH is unimolecular in aqueous solvents. In Part VI (J., 1936, 225) it was proved in the example of *iso*propyl bromide that when Alk = Pr^{β} the bimolecular and unimolecular reactions have comparable velocities, and are present together under conditions convenient for measurement. We now extend the investigation to *iso*propyl chloride and iodide, so that we can compare the rates of the constituent reactions for the three *iso*propyl halides. As with *iso*propyl bromide so with the chloride and iodide there is an accompanying elimination of olefin, and this is bimolecular. The separate rate constants of the olefin eliminations having been evaluated, we can compare these also for the three halides. The results also permit comparisons between the bimolecular rates for the *iso*propyl halides and the total (bimolecular) rates for the ethyl halides, and, account being taken of the work described in Part VIII (following paper), between the unimolecular rates for the *iso*propyl halides and the total (unimolecular) rates for the *tert*.-butyl halides. Measurements have been made at different temperatures; the temperature coefficients of the several reactions can thus be compared, and their dependence on the nature of the alkyl group and of the halogen atom can be deduced.

We shall as usual designate the bimolecular substitution and elimination S_N2 and E2 respectively, and the unimolecular substitution S_N1. The method employed in the evaluation of the separate rate constants was similar to that described in Part VI (*loc. cit.*). The first-order reaction was isolated by the use of low concentrations of hydroxide ions (neutral or acidic solutions), while the olefin elimination and the total reaction were measured in fairly concentrated alkaline solutions. The solvents used, "60%" and "80%" aqueous ethyl alcohol, are denoted by A and B respectively in Table I, which records the velocity coefficients at 80·0° for the three *iso*propyl halides. The units of k are l./g.-mol.-sec. or $sec.^{-1}$ as the case may be. The right-hand column contains results by Grant and Hinshelwood (J., 1933, 258) for the total bimolecular reaction, S_N2 + E2, of the corresponding ethyl halides in 100% ethyl alcohol (C).

TABLE I.

Velocity Coefficients (10^4k) *of Hydrolysis* * *of Ethyl and* iso*Propyl Halides at* 80°.

	S_N2.		E2.		S_N1.		S_N2 + E2.	
Solvent.	A.	B.	A.	B.	A.	B.	C.	
Halide: $Pr^{\beta}Cl$	—	0·136	—	0·189	—	0·00889	EtCl ...	7·73
Halide: $Pr^{\beta}Br$	3·56	4·97	5·01	7·805	0·836	0·289	EtBr ...	226
Halide: $Pr^{\beta}I$	8·18	—	23·14	—	1·16	—	EtI ...	460

* Alcoholysis also takes place but this does not affect any of the deductions drawn in this paper (cf. Part VI and the experimental section).

Two points stand out clearly in this comparison. The first is that, despite the difference of solvent and the fact that Grant and Hinshelwood record only the collective constants for the total reactions of the ethyl halides, the bimolecular substitution is much slower for the *iso*propyl halides than for the ethyl halides. This has been discussed in some detail in relation to the bromides in Part VI, and all that need be added is that the relation is general for the three halides, and can be explained on the lines already considered.

The second point is that for all these reactions there is a much larger velocity difference between chloride and bromide than between bromide and iodide. This was also a feature of the early results of Conrad and Bruckner (*Z. physikal. Chem.*, 1889, 4, 631) relating to the action of sodium ethoxide on alkyl halides in alcoholic solution (RBr/RCl = *ca.* 60 and RI/RBr = *ca.* 2 for a number of alkyl groups), and a similar irregular sequence was

recorded recently by Bergmann, Polanyi, and Szabo (*Trans. Faraday Soc.*, 1936, 32, 843) for the reaction of sodium iodide with the β-*n*-hexyl halides in acetone solution (Br/Cl = 620, I/Br = 19). This raises some very complicated questions, but we may point out that, whereas the C—Hal. bond strengths and stretching force-constants vary in a fairly regular manner in the series Cl, Br, I, the polarisabilities of these atoms vary irregularly, the large separation being between bromine and iodine. Bond strengths and stretching force-constants relate to dissociation into neutral atoms or radicals in the absence of a solvent, and hence it is only reactions taking place without electron transference in the gaseous phase that would be expected, *a priori*, to be represented by nearly equally spaced velocity ratios, on the basis of the variation in bond strengths and force-constants. Reactions in solution of the type under discussion will be profoundly influenced by polarisation, polarisability and solvation factors, and it is not surprising that there does not appear to be any obvious relationship between bond strengths or force-constants and velocity in these reactions. The dependence of the energy required for electron transference on halogen polarisability might conceivably produce the observed spacing of the rates.

It remains for us to examine the behaviour of the Arrhenius critical energy in relation to these measurements. The value of the parameters B and E in the equation $k = Be^{-E/RT}$ are recorded in Table II; E is in kilo-cals. and B in l./g.-mol.-sec. or sec.$^{-1}$, according as the reaction is bimolecular or unimolecular.

TABLE II.

Arrhenius Parameters B *and* E *for Hydrolysis of Ethyl and* iso*Propyl Halides.*

	E.							
	S_N2.		E2.		S_N1.			S_N2 + E2.
Solvent.	A.	B.	A.	B.	A.	B.		C.
Halide { $Pr^{\beta}Cl$	—	23·0	—	24·8	—	23·2	EtCl	23·0
Halide { $Pr^{\beta}Br$	20·8	21·7	22·1	22·6	22·7	23·2	EtBr	21·0
Halide { $Pr^{\beta}I$	20·7	—	22·2	—	23·8	—	EtI	21·0
	$10^{-9}B$.							
Halide { $Pr^{\beta}Cl$	—	2·6	—	48	—	0·21	EtCl	149
Halide { $Pr^{\beta}Br$	2·7	14	25	83	9·0	6·5	EtBr	241
Halide { $Pr^{\beta}I$	4·9	—	141	—	62	—	EtI	508

We confine discussion here to the bimolecular reactions, because the following paper contains a further experimental study of unimolecular reactions of the type S_N1.

It has been emphasised in previous papers that no simple significance can be attached to the allocation of small velocity differences between the parameters of the Arrhenius equation. However, for reactions S_N2 and E2 of the *iso*propyl halides, and for the total reaction S_N2 + E2 of the ethyl halides, the fairly large rate differences between the chlorides and the bromides appear chiefly as differences in the critical energies (cf. Grant and Hinshelwood, *loc. cit.*). Between bromides and iodides there is no difference of any account in the E values or, of course, in the B factors, since the velocities themselves are insufficiently separated. On the other hand, as far as the comparisons can be made (for it is to be noted that the solvents are different), the velocity difference between the bimolecular substitution (S_N2) for the *iso*propyl halides and the total reaction (largely S_N2) for the ethyl halides appears mainly as a difference in B for the three halides examined. It was noted in Part VI that the temperature coefficient of E2 was greater than that of S_N2 in the case of *iso*propyl bromide, and we now see that this is also true of the chloride and the iodide.

EXPERIMENTAL.

Materials.—The *iso*propyl chloride was dried over phosphoric oxide and fractionated from a little anhydrous sodium carbonate, the fraction, b. p. 36·5°/760 mm., being used for the measurements. The *iso*propyl iodide was shaken with mercury to remove iodine, dried over phosphoric oxide, and fractionated twice, b. p. 89·5°/760 mm. It was kept in a brown bottle in the dark, and no further coloration took place. The "60%" aqueous alcohol was made by mixing 6 l. of lime-dried alcohol with 4 l. of water, and the "80%" aqueous alcohol by mixing 8 l. of the alcohol with 2 l. of water.

Velocity Measurements.—The thermostats at 50°, 70°, and 90° could be set to within 0·05°. The one kept at 109·6° was subject to larger fluctuations over short periods of time, but the average temperature over 15-min. intervals was sensibly constant. The initial concentration of the *iso*propyl halides was determined by introducing an accurately weighed quantity into the appropriate medium (initially neutral or strongly alkaline) and making up to a standard volume; where possible this was checked by observation of the asymptotic value of the halide-ion concentration after long intervals. For each run a number of small, thin-walled, glass tubes, each containing 5-c.c. portions of the reaction mixture, were sealed, and heated in the thermostat, and at successive intervals of time a tube was removed, quickly cooled, and opened. The contents were estimated either by the change in the acidity of the solution, or by a modified silver nitrate titration. In the former method, the tubes were broken under about 100 c.c. of absolute alcohol and the acid was titrated with, *e.g.*, 0·02*N*-sodium hydroxide, lacmoid being used as indicator. The latter method is suitable for hydrolysis in the presence of excess of alkali. In the case of *iso*propyl chloride the method was as follows: a tube is broken under ether, and the alkali neutralised with aqueous sulphuric acid; nitric acid, excess of standard silver nitrate solution, and the indicator (ferric alum) are added, and the excess of silver ions is estimated by titration with standard ammonium thiocyanate. The ether plays a dual rôle—it extracts the unreacted *iso*propyl chloride, and thus minimises further hydrolysis and reaction with silver nitrate, and it improves the end-point by coagulating the silver chloride formed. In the case of *iso*propyl iodide the method had to be modified, as direct titration with silver nitrate, even in the presence of ether, led to a reaction with the unchanged halide. The method adopted was as follows: the tube was broken under carbon tetrachloride, which dissolves the organic iodide; the inorganic iodide was then extracted twice with water, and the aqueous layer was neutralised with aqueous sulphuric acid and titrated with silver nitrate, eosin being used as indicator.

The propylene was estimated as described in Part VI (*loc. cit.*).

Estimation of iso*Propyl Ethyl Ether.*—Large-scale experiments were carried out on the hydrolysis of the chloride only. After completion of the reaction, the product was carefully fractionated, and the first fraction, b. p. below 70°/760 mm., was refluxed with sodium to remove water and alcohol. The ether was distilled into a cooled, tared receiver, and weighed. In acidic solution it was estimated that *iso*propyl ethyl ether was formed to the extent of about 30 mols.%, and in alkaline solution to the extent of 5 mols. %, of which 1% was due to S_N1.

The First-order Reactions.—iso*Propyl chloride.* In a preliminary run it was observed that the acid titre increased to a maximum and then decreased (Table III). A maximum corresponding to incomplete reaction might, of course, have been due to a reversible hydrolysis: $Pr^{\beta}Cl + H_2O \rightleftharpoons Pr^{\beta}OH + HCl$, but the subsequent decrease was obviously due to another cause. It was traced to a reaction between the hydrochloric acid and the ethyl alcohol medium [Table IV (*a*)], and it was shown that the analogous reaction with the *iso*propyl alcohol formed in the hydrolysis must be inappreciable in comparison [Table IV (*b*)]. In order to determine the first-order rate constant, we therefore had to resort to the "initial velocity" method. Initially neutral solutions were used, and the reaction was followed to the extent of about 30% by

TABLE III.

Demonstrating the decrease in the concentration of HCl in the hydrolysis of *iso*propyl chloride in "80%" aqueous ethyl alcohol. Temp. 109·65°. Initially $[Pr^{\beta}Cl] \sim N/5$ and [HCl] = 0. [HCl] expressed as equivalent c.c. of 1·475*N*/10-NaOH per 5 c.c. of solution.

t (hrs.)	1·00	2·00	6·00	10·00	25·70	80·00	100·00
[HCl]	3·25	6·20	16·25	22·45	32·70	30·80	29·90

TABLE IV.

Demonstrating the reaction between hydrochloric acid and (*a*) "80%" aqueous ethyl alcohol, (*b*) "80%" aqueous ethyl alcohol + *iso*propyl alcohol. Temp. 109·65°. Initially [HCl] ~ *N*/10. [HCl] expressed as equivalent c.c. of $N/20\text{-}NH_4CNS$ per 5 c.c. of solution. *X* = [HCl] reacted (in the same units).

	(*a*) $[Pr^{\beta}OH] = 0$.		(*b*) $[Pr^{\beta}OH] \sim N/5$.	
t (hrs.).	[HCl].	*X*.	[HCl]	*X*.
0·00	30·80	—	30·30	—
3·50	26·80	4·00	26·25	4·05
10·00	20·65	10·15	20·05	10·25
20·00	13·60	17·20	10·25	17·20

determination of the increase in acidity. The unimolecular constant was not very seriously affected by the secondary reaction over the initial range (Table V), and the true value was found by a graphical extrapolation to zero time of the results of at least two separate runs. Measurements were made at 90·0° and 109·65°. The first-order constants may be taken as $k_{90\cdot0^\circ}$ (hr.$^{-1}$) = 0·00798 and $k_{109\cdot65^\circ}$ (hr.$^{-1}$) = 0·0416.

TABLE V.

Illustrative record of two out of a number of experiments to determine the unimolecular rate constants of the hydrolysis of *iso*propyl chloride in "80%" aqueous alcohol at two temperatures. Initially [Pr$^\beta$Cl] ~ $N/5$. Samples of 5 c.c. titrated. [Pr$^\beta$Cl] expressed as equivalent c.c. of 1·475N/100-NaOH. k_1 = first-order rate constant in hours^{-1}, calculated from the formula $k_1 = (1/t) \cdot \log_e\{a/(a-x)\}$, where a is the initial concentration of *iso*propyl chloride and x the decrease in concentration.

Temp. 90·0°.			Temp. 90·0°.			Temp. 109·65°.			Temp. 109·65°.		
t (hrs.).	[Pr$^\beta$Cl].	10^3k_1.	t(hrs.).	[Pr$^\beta$Cl].	10^3k_1.	t (hrs.).	[Pr$^\beta$Cl].	10^2k_1.	t (hrs.).	[Pr$^\beta$Cl].	10^2k_1.
0·00	73·95	—	16·10	65·40	7·62	0·00	73·50	—	3·10	64·90	4·03
4·00	71·65	7·88	21·17	63·05	7·52	0·50	72·00	4·14	4·55	61·05	4·07
7·00	70·05	7·74	27·00	60·00	7·74	0·75	71·40	3·87	6·00	57·70	4·03
10·00	68·50	7·74	42·50	54·25	7·28	1·00	70·70	3·89	8·01	54·35	3·77
12·25	67·45	7·62				1·51	69·10	4·09	10·00	51·50	3·54
						2·00	67·75	4·07			

iso*Propyl iodide.*—In "80%" aqueous ethyl alcohol appreciable quantities of iodine were formed after 5—10% of reaction had taken place. This may result either from the oxidation of the hydriodic acid produced in the hydrolysis, or from a non-hydrolytic decomposition of the alkyl iodide. Determinations of the amounts of free iodine formed when N/10-solutions in "80%" aqueous ethyl alcohol of (a) hydriodic acid and (b) *iso*propyl iodide were left under identical conditions showed that by far the greater amount results from direct decomposition of the *iso*propyl iodide. Special precautions to exclude the access of light and air, such as passing a stream of nitrogen through the solution before sealing the tubes, and enclosing them in black bags, effected a decrease in the iodine content; but the application of the initial velocity method to the results met with little success, even after applying a correction for the iodine (estimated by titration with thiosulphate). In "60%" aqueous ethyl alcohol, however, the hydrolytic reaction was greatly facilitated at the expense of the decomposition; and it was possible to follow 50% of the reaction satisfactorily by determination of the increase in acidity, the iodine formation being unimportant to that point. Light and oxygen were again excluded as far as possible, and under these conditions a good unimolecular constant was obtained (Table VI). Measurements were made at 50·0° and 69·9°.

TABLE VI.

Demonstrating the first-order rate constant of the hydrolysis of *iso*propyl iodide in "60%" aqueous alcohol. Temp. 50·0°. Initially [Pr$^\beta$I] ~ $N/10$. Samples of 5 c.c. titrated. [Pr$^\beta$I] expressed as equivalent c.c. of 1·475N/100-NaOH. k_1 = first-order constant in hours^{-1}, calculated in the usual way.

t (hrs.).	[Pr$^\beta$I].	10^2k_1.	t (hrs.).	[Pr$^\beta$I].	10^2k_1.
0·00	33·83	—	23·00	22·68	1·74
3·50	31·80	1·77	26·60	21·08	1·78
7·00	29·92	1·76	30·00	19·73	1·80
9·10	28·73	1·79	34·65	18·18	1·79
11·95	27·28	1·80	47·20	14·78	1·76
				Average	1·77

Another run at 50·0° gave k_1 = 0·0178, and two runs at 69·9° gave k_1 = 0·152 and 0·153.

The Total Second-order Reaction.—The hydrolysis of the chloride and the iodide may be discussed together in this connection as the treatment was the same in both cases with the exception of the experimental methods of analysis already discussed. The method of calculation is the same as that described in Part VI. It is necessary to calculate the second-order constant, given the first, from observations of the total reaction. A bimolecular "constant" K_2 is calculated from the formula $K_2 = \frac{1}{t(b-a)} \cdot \log_e \frac{b\,(a-x)}{a\,(b-x)}$, where a and b are the initial concentrations of *iso*propyl halide and sodium hydroxide respectively, and x is the decrease in concentration after time t; the true bimolecular constant k_2 is then obtained by applying a correction for the simultaneous unimolecular reaction (constant = k_1). The relationship is $k_2 = K_2 - k_1/(b-x) + t(dK_2/dt)$ and, as long as most of the reaction is of the second order, the last term can often be neglected. Table VII contains an illustrative record of two out of a number of experiments to

determine the bimolecular constant, together with the average constants obtained in this set of measurements.

TABLE VII.

Illustrating determination of bimolecular rate constants. "Corr. k_1" signifies the correction to be applied to K_2 in order to deduce the true second-order constant k_2. K_2 and k_2 are in l./g.-mol.-hour and k_1 is in hours^{-1}.

(*a*) iso*Propyl chloride.*

Solvent "80%" aqueous ethyl alcohol. Temp. 70·0°. Initially [NaOH] ~ 0·8N and [$Pr^{\beta}Cl$] ~ 0·2N. [NaOH] and [$Pr^{\beta}Cl$] expressed in c.c. of N/20-NH_4CNS per 5 c.c. of solution.

t (hrs.).	[$Pr^{\beta}Cl$].	[NaOH].	10^2K_2.	"Corr. k_1."	10^2k_2.	t (hrs.).	[$Pr^{\beta}Cl$].	[NaOH].	10^2K_2.	"Corr. k_1."	10^2k_2.
0·00	20·55	83·00	—	—	—	17·10	11·50	73·95	4·42	0·0017	4·25
3·00	18·35	80·80	4·69	0·0016	4·53	23·25	9·50	71·95	4·41	0·0018	4·23
7·00	15·95	78·40	4·57	0·0016	4·41	26·00	8·65	71·10	4·46	0·0018	4·28
11·40	13·85	76·25	4·48	0·0016	4·32	37·00	6·70	69·15	4·13	0·0018	3·95
16·00	12·15	74·60	4·28	0·0017	4·11	50·10	4·40	66·85	4·31	0·0018	4·13
										Average	4·25

Another run at 70·0° gave k_2 = 0·0429, and two runs at 90·0° gave k_2 = 0·299 and 0·301.

(*b*) iso*Propyl iodide.*

Solvent "60%" aqueous alcohol. Temp. 69·85°. Initially [NaOH] ~ 0·8N and [$Pr^{\beta}I$] ~ 0·1N. [NaOH] and [$Pr^{\beta}I$] expressed in c.c. of N/40-$AgNO_3$ per 5 c.c. of solution.

t (mins.).	[$Pr^{\beta}I$].	[NaOH].	K_2.	"Corr. k_1."	k_2.	t (mins.).	[$Pr^{\beta}I$].	[NaOH].	K_2.	"Corr. k_1."	k_2.
0·00	18·05	157·65	—	—	—	11·50	9·10	148·70	4·69	0·20	4·49
1·50	16·45	156·05	4·73	0·19	4·54	16·00	7·05	146·65	4·67	0·21	4·46
3·50	14·65	154·25	4·59	0·20	4·39	22·50	4·80	144·40	4·73	0·21	4·52
6·00	12·55	152·15	4·69	0·20	4·49	30·00	3·10	142·70	4·77	0·21	4·56
8·50	10·90	150·50	4·63	0·20	4·43					Average	4·49

Another run at 69·85° gave k_2 = 4·48, and two runs at 50·0° gave k_2 = 0·630 and 0·626.

The Separate Second-order Reactions.—In order to find the ratio in which the second-order constant k_2 should be split up between the second-order substitution and the elimination, it is necessary to estimate the amount of olefin formed, and also to calculate the proportion $x_1/(x_1 + x_2)$ of the total reaction $x = x_1 + x_2$ which has proceeded through the unimolecular route. The formula used for the calculation (cf. Part VI) is

$$x_1/(x_1 + x_2) = x_1/x = k_1/\{k_1 + k_2(b - \tfrac{1}{2}x)\}$$

The results are in Table VIII. Col. 1 records the temperature; col. 2 gives the observed percentage of olefin formed in the completed reaction, each figure representing the mean of at least four determinations. Col. 3 gives the calculated percentage of products formed by the unimolecular substitution; and col. 4 the figures obtained, by difference, for the products formed by the bimolecular substitution. The last two columns contain the factors which, when multiplied into the total second-order rate constants (Table VII), will give the rate constants for the two separate bimolecular reactions.

TABLE VIII.

Temp.	E2 (%) (obs.).	S_N1 (%) (calc.).	S_N2 (%) (diff.).	$\frac{S_N2}{S_N2 + E2}$.	$\frac{E2}{S_N2 + E2}$.
(*a*) *iso*Propyl chloride in "80%" aqueous ethyl alcohol. Initial [$Pr^{\beta}Cl$] ~ 0·2N. Initial [NaOH] ~ 0·8N.					
70·0	54·90	3·90	41·20	0·429	0·571
90·0	58·40	3·60	38·00	0·394	0·606
(*b*) *iso*Propyl iodide in "60%" aqueous ethyl alcohol. Initial [$Pr^{\beta}I$] ~ 0·1N. Initial [NaOH] ~ 0·8N.					
50·0	67·20	3·70	29·1	0·302	0·698
69·85	70·30	3·30	26·4	0·273	0·727

Summary of Rate Constants.—Table IX summarises all the rate constants determined in this investigation. Table IX (*a*) gives the mean values of the unimolecular rate constants, k_1 (reaction S_N1), in hours^{-1} for the temperatures investigated. Table IX (*b*) and (*c*) contain the rate constants of the bimolecular substitution (reaction S_N2) and the bimolecular elimination (reaction E2) respectively, obtained by decomposing the total bimolecular rate constants of Table VII in accordance with the factors given in Table VIII. The units are l./g.-mol.-hour.

TABLE IX.

(a) Reaction S_N1.		(b) Reaction S_N2.		(c) Reaction E2.	
Temp.	k_1.	Temp.	k_2.	Temp.	k_2.
A. *iso*Propyl chloride in " 80% " aqueous ethyl alcohol.					
90·0°	0·00798	70·0°	0·0183	70·0°	0·0244
109·65	0·0416	90·0	0·118	90·0	0·182
B. *iso*Propyl iodide in " 60% " aqueous ethyl alcohol.					
50·0	0·0178	50·0	0·190	50·0	0·438
69·85	0·153	69·85	1·225	69·85	3·265

The Arrhenius parameters of the several reactions are given in the introduction.

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UNIVERSITY COLLEGE, LONDON. [*Received, April 24th*, 1937.]

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249. *Mechanism of Substitution at a Saturated Carbon Atom. Part VIII. Hydrolysis of* tert.*-Butyl Halides.*

By KENNETH A. COOPER and EDWARD D. HUGHES.

Previous study of the unimolecular hydrolysis of *tert.*-butyl chloride is here extended to include *tert.*-butyl fluoride, bromide, and iodide. The peculiar spacing of rates observed for the halides of the *iso*propyl series (preceding paper) is reproduced in the *tert.*-butyl compounds; and, consistently with considerations of electronic structure, the rates for the tertiary halides are greater than for the corresponding secondary halides by factors of the order of 10^4. The greater part of this difference is represented by a variation in the *B*-factor of the Arrhenius equation, $k = Be^{-E/RT}$. In 80% aqueous ethyl alcohol the *B*-factors for the *tert.*-butyl halides have the "normal" values of *ca.* 10^{13}, but the hydrolyses of the *iso*propyl halides in the same medium may be classified as " slow " unimolecular reactions, the *B* factors being of order 10^9 only. The hydrolyses of the *tert.*-butyl halides can be made " normal " or " slow " according to the solvent in which they are carried out. The results are discussed in relation to recent theories of reaction kinetics in solution.

IN a previous paper (Hughes, J., 1935, 255) it was shown that the hydrolysis of *tert.*-butyl chloride in aqueous alcohol or aqueous acetone was of the first order with respect to the chloride and of zero order with respect to hydroxide ions. The explanation given was that the rate-controlling process is the ionisation of the alkyl halide, and that this is succeeded by the rapid decomposition of a solvent molecule by the *tert.*-butyl cation; the correctness of this interpretation is borne out by the investigation described in Part IX (following paper). The hydrolysis is an example of the form of substitution which we designate S_N1.

In this paper we generalise the kinetic investigation to include the other *tert.*-butyl halides, although, on account of certain experimental difficulties, the fluoride has been studied less fully and accurately than the bromide and iodide. All four halides hydrolyse in a unimolecular fashion, with a rate independent of alkalinity or acidity, although the velocities vary over a very wide range. The rates increase from the fluoride to the iodide, but, although for the fluoride and chloride they differ by a factor of roughly 10^5, yet for the chloride and bromide the factor is about 40, and for the bromide and iodide about 2·5. A similar variation of rate as between chloride, bromide, and iodide was also found for the S_N1 part of the hydrolysis of the *iso*propyl halides (Part VII, preceding paper). The rates for the *tert.*-butyl halides are greater than those for the corresponding *iso*propyl halides by factors all of the order 10^4, consistently with considerations of electronic structure set forth in earlier papers of this series. In the following table we give for comparison the unimolecular rate constants for the reactions at 25° in " 80% " aqueous ethyl alcohol, *i.e.*, the solvent prepared by mixing 80 vols. of anhydrous ethyl alcohol with 20 vols. of

water. The figures for *tert.*-butyl chloride come from Hughes's investigation (*loc. cit.*), and those for the *iso*propyl halides from Part VII, a calculation or estimate being applied where necessary to take account of the difference between the experimental conditions and those of the comparison. The units of k and B are sec.$^{-1}$, and E is in kilo-cals.

Rate Constants and Arrhenius Parameters of Unimolecular Hydrolysis of iso*Propyl and* tert.*-Butyl Halides in 80% Aqueous Ethyl Alcohol.*

	*iso*Propyl halides.			*tert.*-Butyl halides.		
	$k_{25°}$*.	B.	E.	$k_{25°}$.	B.	E.
Fluoride	—	—	—	*ca.* 10^{-10} ‡	—	—
Chloride	$1{\cdot}9 \times 10^{-9}$	$2{\cdot}1 \times 10^{8}$	23·2	$9{\cdot}14 \times 10^{-6}$	$7{\cdot}8 \times 10^{11}$	23·1
Bromide	$5{\cdot}8 \times 10^{-8}$	$6{\cdot}5 \times 10^{9}$	23·2	$3{\cdot}74 \times 10^{-4}$	$2{\cdot}0 \times 10^{13}$	22·8
Iodide	$6{\cdot}2 \times 10^{-8}$	$4{\cdot}5 \times 10^{10}$ †	24·3 †	$9{\cdot}01 \times 10^{-4}$	$2{\cdot}6 \times 10^{13}$	22·4

* Calculated from experiments at higher temperatures.
† Estimated from experiments in " 60% " alcohol.
‡ Roughly estimated from experiments at a higher temperature.

The rate constants for the *tert.*-butyl halides are composite inasmuch as a small proportion of the reaction measured is due to olefin elimination * (cf. this vol., p. 1280), and ethoxylation accompanies hydroxylation. However, we are of the opinion that the rate-controlling process in all these reactions is the ionisation of the alkyl halide, and, as we are here concerned with the rate of ionisation rather than with the fate of the ions, the figures recorded in the table form the proper basis for comparison.

In the case of *tert.*-butyl bromide and iodide we have measured the temperature coefficient of reaction velocity, and applied the equation, $k = Be^{-E/RT}$. The values of B and E thus obtained, together with the available values of these quantities for the *iso*propyl halides and *tert.*-butyl chloride, are included in the table.

The most noteworthy feature of these figures is the close grouping of all the E-values around 23 kilo-cals. The greater part of the difference in the rate constants can be represented by means of variations in the B factors. One would expect that structural changes of the type investigated would cause a variation in both parameters, and we believe that the zero-point critical energy does vary as between the *iso*propyl and *tert.*-butyl halides, and as between chlorides, bromides, and iodides, but for reasons indicated elsewhere (Hughes, Ingold, and Shapiro, J., 1936, 225) we are not able to deduce this from the Arrhenius critical energies. In this connection it may be noted that Evans and Polanyi (*Trans. Faraday Soc.*, 1936, **32**, 1333) have concluded that, in the case of related reactions in solution, a sequence of zero-point critical energies, calculated from considerations of atomic mechanism, cannot always be expected to bear a simple relationship to the observed critical energies, if, as is usual, the latter are measured at ordinary temperatures. Indeed, they infer that the quantity which can be most easily related to the zero-point critical energy is log k (k = the reaction velocity constant)—a conclusion which is in entire agreement with our experience. The normal value of the B factor of a unimolecular reaction is about 10^{13} sec.$^{-1}$ (Polanyi and Wigner, *Z. physikal. Chem.*, 1928, **139**, 439), and this is practically the value we find for the reactions of the *tert.*-butyl halides. For the *iso*propyl halides the B values are smaller by 10^{3}—10^{4}, so that these reactions may be said to qualify for inclusion in the category of " slow " unimolecular reactions. In the language of the transition state theory, a greater restriction is placed on the co-ordinates of the transition state in the reactions of the *iso*propyl than in those of the *tert.*-butyl halides. One can see in a general way that a more facile electron supply to the halogen atom would be expected to increase the variation permissible in the co-ordinates of those molecules, particularly the solvent molecules, which are concerned in an ionisation. Viewing the matter from a somewhat different standpoint, we may say that the *iso*propyl halides require a more specific orientation of solvent molecules to produce a field capable of stabilising the polar transition complex (cf. Hinshelwood and Winkler, J., 1936, 371). The variation of the B factors between different halides belonging to the same alkyl group is smaller,

* The olefin elimination was not detected in the earlier investigation on *tert.*-butyl chloride (*loc. cit.*).

viz., 10—10^2 over the range chlorides to iodides, and the trend is towards larger values for the heavier halogens. The large difference of rate between chloride and fluoride could not be analysed in terms of the Arrhenius parameters on account of the inactivity and volatility of *tert.*-butyl fluoride, but the phenomenon would appear to merit investigation in a system more easily amenable to experimental treatment.

We expect solvent co-ordinates to be especially important in the definition of the transition states of reactions dependent on ionisation, and we can illustrate the truth of this assumption by reference to an effect which, in its magnitude, is unparalleled in any bimolecular hydrolysis with which we are acquainted. When the solvent used in the hydrolysis of *tert.*-butyl bromide is changed from 80% ethyl alcohol to 95% acetone, the Arrhenius critical energy undergoes only an insignificant change, whilst the B factor falls from $2{\cdot}0 \times 10^{13}$ to $9{\cdot}2 \times 10^{10}$. A similar effect was observed in the influence of the solvent on the hydrolysis of *tert.*-butyl chloride (Hughes, *loc. cit.*). It is clear that the reaction is one which can be made " normal " or " slow," according to the solvent in which it is carried out. This shows that the replacement of a more ionising by a less ionising medium places narrower limits on the co-ordinates defining the transition state, a conclusion which would be unintelligible unless these co-ordinates included in an essential way those of solvent molecules.

These observations support the view, now becoming prevalent amongst investigators in the field of reaction kinetics, that the so-called " slow " reactions are but extremes in a continuous range of reactions in which the B-factors may vary within wide limits. Even in reactions of one type, such as the one herein discussed, we could traverse this range by making suitable changes in the structure of the reactants and in the properties of the medium.

EXPERIMENTAL.

tert.-*Butyl Fluoride.*—A mixture of *tert.*-butyl alcohol (50 g.) and aqueous hydrofluoric acid (50—60%, 50 g.) was warmed to 60° in a copper flask. The volatile product was condensed in a freezing mixture of ice and salt, treated with bromine at 0° to remove an unsaturated impurity (probably *iso*butylene), and distilled, head and tail fractions being neglected. The fluoride is a gas at room temperature; the liquid has b. p. *ca.* 13°/760 mm. On prolonged standing at 0° it eliminates hydrogen fluoride and forms unsaturated products—a reaction which is greatly accelerated by phosphoric oxide or sulphuric acid.

tert.-Butyl chloride was prepared as described in Part V (*loc. cit.*).

tert.-Butyl bromide was prepared by a modification of Norris's method (*Amer. Chem. J.*, 1907, **38**, 641). The crude bromide, which separates when *tert.*-butyl alcohol is mixed with concentrated aqueous hydrobromic acid (d 1·7), was removed, saturated with gaseous hydrogen bromide, dried over anhydrous sodium carbonate, and distilled from the same reagent, b. p. 72°/760 mm.

tert.-*Butyl Iodide.*—Dry hydrogen iodide, prepared by adding concentrated aqueous hydriodic acid (d 1·9) to phosphoric oxide mixed with red phosphorus, was passed into *tert.*-butyl alcohol at room temperature. When the separation into two layers appeared to be complete, the organic layer was again saturated with hydrogen iodide, dried over anhydrous sodium carbonate, and fractionated under reduced pressure.

Media.—Commercial absolute ethyl alcohol was dried by the method of Lund and Bjerrum (*Ber.*, 1931, **64**, 210), and fractionated. The " 50% " aqueous ethyl alcohol was made by mixing equal volumes of this alcohol and water, and the " 80% " aqueous alcohol by mixing 8 l. of alcohol with 2 l. of water. The " 95% " acetone was made by mixing 950 c.c. of acetone, purified by the method of Conant and Kirner (*J. Amer. Chem. Soc.*, **1924**, **46**, 246), with 50 c.c. of water. The unimolecular hydrolyses investigated are extremely sensitive to changes in the composition of the medium; but in all cases in which a strict comparison of rates was desirable, portions of the same sample of the aqueous medium were used.

Isolation of Ethyl tert.-*Butyl Ether.*—*tert.*-Butyl bromide (25 c.c.) was diluted to 250 c.c. at 25° with " 80% " aqueous ethyl alcohol. When the reaction was complete the mixture was neutralised with sodium carbonate and distilled. The first fraction, b. p. below 82°, was diluted with water, and the small upper layer containing ethyl *tert.*-butyl ether was removed, boiled under reflux with sodium, and distilled, b. p. 69°/760 mm. (Found: C, 70·0; H, 13·5. Calc.: C, 70·6; H, 13·7%). The yield, calculated from the weight of *tert.*-butyl bromide used, was 13 mols. %, but this is a minimum figure for the amount of ether formed.

Estimation of Olefin.—By employing the method of analysis described in Part VI (Hughes, Ingold, and Shapiro, J., 1936, 225), olefin was detected in the hydrolysis of *tert.*-butyl chloride, bromide, and iodide (*tert.*-butyl fluoride was not examined). In " 80% " aqueous ethyl alcohol at 25° the yield was *ca.* 15% of the total hydrolysis.

Kinetic Measurements.—The thermostats could be set to within 0·05°. Two methods of procedure were employed. In the first, a suitable quantity of the halide was dissolved in the initially neutral or alkaline medium at the desired temperature, and, at suitable intervals, 5 c.c. portions were withdrawn, run into 100 c.c. of cold absolute alcohol or acetone to stop the reaction, and analysed by titration against standard acid or alkali as required. In the second, portions of 5 c.c. of the reaction mixture were enclosed in sealed tubes, which were placed in the thermostat for known times and then broken under absolute alcohol, and estimated. The latter method was used where there was a danger of loss by evaporation. The reactions proceeded to completion with the exception of the hydrolysis of *tert.*-butyl bromide in 95% acetone. In this case a stationary state was reached after 95% of the halide had been hydrolysed, but the initial rate constants were not affected.

Hydrolysis of tert.-*Butyl Bromide.*—The results are summarised in Table I. Measurements were made in " 80% " aqueous ethyl alcohol (Sample A) at three temperatures (Expts. 1, 2, and 3) and in " 95% " acetone at two temperatures (Expts. 6 and 7). In the former medium the method of pipetting the samples was used, and in the latter the sealed-tube method. The first-order rate constants are calculated from the formula $k_1 = (1/t).\log_e\{a/(a - x)\}$, where a is the initial concentration of *tert.*-butyl bromide and x the decrease in its concentration. In " 80% " alcohol, a was found by determining the asymptotic value of x after long times, and in " 95% " acetone it was obtained by running 5 c.c. portions of the reaction mixture into about 50 c.c. of water to complete the hydrolysis and estimating acidity in the usual way. Expts. 4 and 5 show that the first-order constant in " 80% " aqueous ethyl alcohol (sample B) is the same in acid and alkaline solution. In " 95% " acetone the Arrhenius equation takes the form $k = 9{\cdot}16 \times 10^{10}e^{-22{,}700/RT}$, where k and B are in sec.$^{-1}$ and E is in cals. The Arrhenius parameters for the hydrolysis in " 80% " alcohol are given in the introduction. The results of two typical experiments are recorded in detail in Table II.

Hydrolysis of tert.-*Butyl Iodide.*—Measurements were made in " 80% " aqueous ethyl alcohol (Sample A) at two temperatures (Table I, Expts. 8 and 9) and in acid and alkaline solutions (Sample C, Expts. 10 and 11). The method of pipetting samples was used, and a was taken as the asymptotic value of x after long times. The Arrhenius parameters are given in the theoretical section.

Hydrolysis of tert.-*Butyl Fluoride.*—Measurements were made in " 50% " aqueous ethyl alcohol at 100° by the sealed-tube method. The reaction is heterogeneous under these conditions (liquid and gaseous phases are present), and the velocity is dependent on the volume of the tubes. Notwithstanding that tubes of approximately equal volumes were used in the experiments recorded, the first-order rate " constants " are erratic. The average constants obtained in two experiments in alkaline solution are shown in Table I (Expts. 12 and 13), and a typical experiment is recorded in detail in Table II. The difference between the two rate constants may be due to the effect of the base on the solubility of the fluoride in the liquid phase. For obvious reasons, only the initial stages of the hydrolysis in initially neutral solution could be examined, but the rate was substantially the same as that in dilute alkaline solution.

TABLE I.

Summary of first-order rate constants. k_1 is in sec.$^{-1}$.

Expt.	Halide.	Medium.	Initial [NaOH].	Temp.	$k_1 \times 10^6$.
1	$Bu^{\gamma}Br$	80% EtOH (A)	—	24·95°	374
2	"	"	—	15·05	100
3	"	"	—	0·10	11·2
4	"	80% EtOH (B)	—	24·95	364
5	"	"	0·14N	"	357
6	"	95% $COMe_2$	—	"	2·10
7	"	"	—	50·0	41·0
8	$Bu^{\gamma}I$	80% EtOH (A)	—	24·95	901
9	"	"	—	0·10	28·8
10	"	80% EtOH (C)	—	25·15	913
11	"	"	0·15N	"	920
12	$Bu^{\gamma}F$	50% EtOH	0·17N	100°	3·0
13	"	"	0·06N	"	7·9

TABLE II.

Illustrating determination of first-order rate constants. $[Bu^{\gamma}X]$ expressed as equivalent c.c. of $N/20$-NaOH (1, 2, and 3) or $N/50$-HCl (4) per 5 c.c. of solution. k_1 is in sec.$^{-1}$.

1. Hydrolysis of $Bu^{\gamma}Br$ in " 80% " alcohol (A) at 24·95°. $[NaOH]_{t=0} = 0$.

t (secs.)	0	326	660	926	1470	1800	2390	3010	3596	5355	∞
$[Bu^{\gamma}Br]$	8·28	7·34	6·51	5·81	4·83	4·31	3·43	2·70	2·09	1·13	0
$k_1 \times 10^4$	—	3·70	3·64	3·82	3·67	3·62	3·69	3·72	3·83	3·72	—

2. Hydrolysis of $Bu^{\gamma}Br$ in " 95% " acetone at 50·0°. $[NaOH]_{t=0} = 0$.

t (mins.)	0	79	146	203	289	375	474	∞
$[Bu^{\gamma}Br]$	11·97	9·85	8·39	7·27	5·89	4·78	4·13	0·64
$k_1 \times 10^5$	—	4·08	4·06	4·10	4·09	4·08	(3·75)	—

3. Hydrolysis of $Bu^{\gamma}I$ in " 80% " alcohol (A) at 0·10°. $[NaOH]_{t=0} = 0$.

t (mins.)	0	29·7	62·4	124	180	240	300	389	∞
$[Bu^{\gamma}I]$	7·60	7·22	6·83	6·17	5·62	5·00	4·51	3·77	0
$k_1 \times 10^5$	—	2·95	2·82	2·80	2·80	2·91	2·90	3·00	—

4. Hydrolysis of $Bu^{\gamma}F$ in " 50% " alcohol at 100°. $[NaOH]_{t=0} = 0·17N$.

t (hrs.)	0	2·90	5·90	8·92	16·42	26·42	51·23	73·37	∞
$[Bu^{\gamma}F]$	15·90	15·42	15·27	14·53	13·48	12·06	8·90	6·40	0
$k_1 \times 10^6$	—	2·94	(1·91)	2·81	2·81	2·92	3·14	3·44	—

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250. *Mechanism of Substitution at a Saturated Carbon Atom. Part IX. The Rôle of the Solvent in the First-order Hydrolysis of Alkyl Halides.*

By LESLIE C. BATEMAN and EDWARD D. HUGHES.

The hydrolysis of an alkyl halide in an aqueous medium will follow the equation for a reaction of the first order if *either* the reaction is " unimolecular," being determined as to rate by an ionisation :

$$\begin{cases} R{\cdot}Hal \xrightarrow[\text{(slow)}]{} R^+ + Hal^- \\ R^+ + OH^- \xrightarrow[\text{(fast)}]{} ROH \end{cases}$$

or it is " bimolecular," being a pseudo-first order reaction involving a solvent molecule as a direct reagent :

$$H_2O + R{\cdot}Hal \longrightarrow H^+ + OH{\cdot}R + Hal^-$$

(The terms " unimolecular " and " bimolecular " refer, as is customary, to the type of mechanism involved, independently of the reaction order.) Indirect methods of distinguishing between the two cases have been based on the kinetic effects of added alkali, of variations in the solvent and of added neutral salts, as well as on the stereochemical effect of the substitution. In this paper a direct kinetic method is elaborated and applied in the case of *tert.*-butyl chloride. It is shown that the rate of reaction of this halide with water in formic acid solution is of the first order, and independent of the (small) concentration of water. The reaction is, therefore, unimolecular, as has already been assumed on other grounds.

IT was shown in Part V (Hughes, J., 1935, 255) that the rate of hydrolysis of *tert.*-butyl chloride in aqueous alcohol or aqueous acetone is independent of the concentration of hydroxide ions : the reaction is of the first order, and its rate constant is the same in acid and in

(*Note added in proof.*) The distinction between order and mechanism does not appear to be fully understood by Taylor, who, in a paper which has just appeared, misrepresents our view of the first-order reactions of methyl, ethyl, *iso*propyl and *tert.*-butyl bromides with aqueous ethyl alcohol. The reactions of the methyl and ethyl halides are bimolecular, and their rates decrease in the order of naming as they should; just as the rates of the essentially unimolecular reactions of *iso*propyl and *tert.*-butyl bromides increase in this order as *they* should. Further discussion of these examples is deferred, but additional examples of bimolecular first-order reactions, with evidence of mechanism, are given in an accompanying paper (this vol., p. 1208).

alkaline solution provided the solvent remains unchanged. The rate increases with the ionising power of the medium : it is greater in more aqueous solvents, and greater in aqueous alcohol than in aqueous acetone. The constitutional and environmental factors which govern the operation of this type of substitution have been discussed (Hughes and Ingold, J., 1935, 244). We now bring fresh evidence to bear on the question of the function of the aqueous solvent.

The general problem to which this paper is a contribution may be expressed in the following form. The discovery that a hydrolysis is kinetically of the first order always opens up the possibility that the process in operation is that which we symbolise as S_N1. This mechanism assumes that the rate-controlling process is the ionisation of the alkyl halide, and that ionisation is succeeded by the rapid reaction of the cation with the solvent molecules :

$$\left.\begin{array}{l} R - X \xrightarrow[\text{slow}]{} R^+ + X^- \\ R^+ + H_2O \xrightarrow[\text{fast}]{} R{\cdot}OH + H^+ \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad S_N1$$

The order of reaction alone, however, does not distinguish between this mechanism and a single-stage bimolecular substitution involving water as a direct reagent, when, as in the experiments to which reference has been made, the quantity of water in the solvent is so large that its concentration is substantially constant.

$$H_2O + R{\cdot}X \longrightarrow R{\cdot}OH + HX \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad S_N2$$

Under the conditions specified, first-order kinetics would still prevail in any one experiment, and any proportionately considerable change in the water contents of the solutions used in different experiments would amount to an alteration of solvent properties.

Several methods of distinguishing between the two mechanisms have already been suggested. It was pointed out (Hughes and Ingold, *loc. cit.*) in relation to the example of *tert.*-butyl chloride that, when in hydrolysis the water molecule functions as a primary reagent, it does so either as an acid or as a base or as both, and that, accordingly, either the stronger acid H_3O^+ or the stronger base $\overline{O}H$ or both act very much more powerfully. This did not happen in the case of *tert.*-butyl chloride and mechanism S_N1 was, therefore, indicated unequivocally. The result of applying this criterion will always be definite and certainly correct when there is no difference of rate as between acid, neutral, and alkaline solutions. The criterion becomes progressively less valuable and certain as the rate of the reaction in the presence of added hydroxide ions increases above that of the acid hydrolysis.

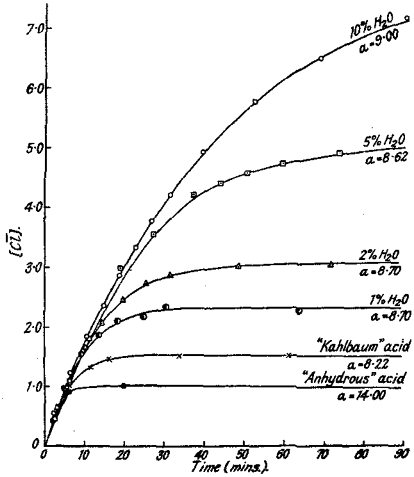
Other criteria, however, have been proposed. We have shown theoretically that in the hydrolysis of alkyl halides by mechanism S_N1 the rate of reaction should increase with the ionising power of the medium, whereas in the hydrolysis by mechanism S_N2 the rate should decrease. This criterion has been applied by Nixon and Branch (*J. Amer. Chem. Soc.*, 1936, **58**, 492) to their experiments on the alcoholysis of triarylmethyl chlorides, and we agree with their statement of the matter. As, however, they refer to a paper from this laboratory dealing with the hydrolysis of 'onium salts, we take this opportunity to make it clear that the particular type of solvent effect which characterises the hydrolysis and alcoholysis of alkyl halides by mechanisms S_N1 and S_N2 does not apply to nucleophilic substitutions generally, or even to all types of hydrolysis. For instance, the hydrolysis of an 'onium cation by mechanism S_N1 would be retarded by an increase in the ionising power of the medium. It is necessary in each individual case to apply the solvent theory of Hughes and Ingold in order to discover the relation of solvent effect to mechanism.

A third criterion can be based on the direction of the neutral-salt effect on reaction velocity. A fourth, based on the steric orientation of substitution, is available when there is asymmetry at the seat of substitution. These matters are, however, dealt with in accompanying papers (this vol., pp. 1196, 1201, 1208, 1252) and require no discussion here.

In this paper we attempt to work out, in the example of *tert.*-butyl chloride, a direct kinetic method of distinguishing between mechanisms S_N1 and S_N2. The method is to use as solvent a substance which has an ionising power towards alkyl halides as great as or greater than that of water; so that small additions of water do not bring about any profound

change in the ionising properties of the medium towards these halides. The mass law can then be applied, and the dependence of the reaction rate on water concentration determined. Formic acid (dielectric constant = 57) has proved a suitable solvent, and the only complicating factors encountered, neither of which presented an insuperable obstacle, arose from the reversibility of the hydrolysis and a reversible side reaction leading to olefin formation.

Measurements have been made at 15° in "anhydrous" formic acid, *i.e.*, formic acid containing a very small amount of water, "Kahlbaum" acid which appears to contain about 0·5% of water, and various synthetic solutions of water in formic acid. The reaction was followed by determining the concentrations of chloride ions. In anhydrous formic acid reaction proceeded to the extent of 7% and no further. We proved the presence at this equilibrium of olefin and hydrogen chloride, but cannot exclude the possibility that



Rate of formation of Cl^- *ions from* tert.*-butyl chloride in formic acid solutions at* 15°: $[Cl^-]$ *expressed in c.c. of* $N/10$-NH_4CNS *per* 5 *c.c. of solution*, "a" = *initial* $[Bu^\gamma Cl]$ *in the same units.*

some part of the observed reaction is due to the presence of traces of water. In Kahlbaum acid the reaction was more extensive, and the progressive addition of water caused a progressive increase in the percentage of reaction at equilibrium. The most significant fact, however, is that the concentration of water had no appreciable effect on the *initial* velocity of formation of chloride ions within the range investigated. This is shown in the figure, in which chloride ion concentration is plotted against time. The initial slopes of all the graphs are the same to within the error of experiment. The subsequent curvature of each graph is due to the reversibility of the reaction. These statements are confirmed by a calculation of the rate constant k_1 of the forward reaction from the integrated equation for the speed of a first-order reaction with second-order reversal $A \underset{k_2}{\overset{k_1}{\rightleftharpoons}} B + C$. The reactions all obey this equation satisfactorily, and the first-order constants k_1 are practically independent of the concentration of water as is shown in Table I.

An examination of the products of reaction showed that the formation of olefin is rapidly suppressed by small additions of water. In all solvents, except the anhydrous acid, olefin

TABLE I.

Formic acid medium.	Anhydrous.	Kahlbaum.	Units % of water added to Kahlbaum acid. 1.	2.	5.	10.
% Reaction at equilm.	7·1	18·5	25·9	34·9	58·0	84·2
10^4k_1 (sec.$^{-1}$)	—	3·84	3·98	3·70	3·66	3·53

production is a minor reaction, and in the presence of the larger concentrations of water it is completely suppressed. In these circumstances the only isolable product is *tert.*-butyl alcohol.

We interpret these results as follows. The rate-determining process in all the media examined is the same, *viz.*, the ionisation of the *tert.*-butyl chloride. The ionising medium for the halide is primarily the formic acid and not the water, and hence the velocity of ionisation is not appreciably changed by increasing the concentration of water within the experimental limits. The fate of the *tert.*-butyl cation depends, however, on the conditions. It may eliminate a proton with the formation of *iso*butylene. If water is present it will largely or exclusively undergo the more facile reaction with a water molecule to produce *tert.*-butyl alcohol. The formation of *tert.*-butyl formate by reaction with formic acid cannot be excluded. But none of these *sequelæ* affects the rate of production of chloride ions, which is determined solely by the rate of electrolytic dissociation of the alkyl halide.

Although the addition of small proportions of water to formic acid does not affect the rate of ionisation of *tert.*-butyl chloride, it does considerably influence the activity of the hydrogen chloride formed, water being more efficient than formic acid for the solvation of a proton. The solvated form of hydrogen chloride $[H_3O]^+Cl^-$ is comparatively inactive in additions to olefins and reactions with alcohols; and hence the rates of these retrograde reactions are strongly affected by water-solvation of the hydrogen chloride; and the equilibrium becomes shifted, as is shown in the figure.

EXPERIMENTAL.

Materials.—The *tert.*-butyl chloride used had b. p. 50·0°/749 mm. The anhydrous formic acid was prepared from " Kahlbaum " formic acid (m. p. *ca.* 7·5°) by fractional freezing, special care being taken to exclude moisture. The technique employed was similar to that described by Smith (J., 1931, 3257) for the purification of formamide. Four freezings usually gave an acid, m. p. 8·4°, which was not improved by further treatment. This m. p. is in good agreement with most of the values recorded in the literature for the m. p.'s of samples purified either by partial freezing or by fractional distillation from an anhydrous salt at low pressures [cf. Garner, Saxton, and Parker, *Amer. Chem. J.*, 1911, **46**, 236 (8·35°); Ewins, J., 1914, **105**, 350 (8·39°); Turner and Pollard, J., 1914, **105**, 175 (8·4°); Kendall, *J. Amer. Chem. Soc.*, 1914, **36**, 1228 (8·5°); Timmermans and Hennaut-Roland, *J. Chim. physique*, 1930, **27**, 401 (8·4°)]. The anhydrous acid deteriorates on keeping, owing to decomposition into carbon monoxide and water which takes place even at low temperatures (Coolidge, *J. Amer. Chem. Soc.*, 1928, **50**, 2166; 1930, **52**, 1874). For this reason it was used as soon as possible after the last freezing. The aqueous mixtures were prepared from Kahlbaum acid, and were made up by volume. The figures recorded in the tables refer to the number of c.c. of *added* water per 100 c.c. of the mixture. Thus " 10% " water in formic acid refers to the mixture resulting when 10 c.c. of water are made up to 100 c.c. with Kahlbaum acid.

Kinetic Measurements.—The temperature throughout was 15·00° ± 0·02°. In the experiments in Kahlbaum and more aqueous acids an approximately measured volume (*ca.* 2 c.c.) of *tert.*-butyl chloride was dissolved in a suitable volume of the solvent (*ca.* 100 c.c.), both being kept in the thermostat before admixture. At suitable intervals 5 c.c. portions of the reaction mixture were withdrawn and run into 50 c.c. of carbon tetrachloride. The carbon tetrachloride solution was extracted twice with 25 c.c. of water, and to the aqueous extracts were added a few drops of concentrated nitric acid, 10 or 20 c.c. (excess) of a standard solution of silver nitrate, the ferric alum indicator, and about 10 c.c. of ether. The excess of silver ions was determined by titration with standard ammonium thiocyanate solution. The presence of ether eliminates the necessity of removing the silver halide [cf. Treadwell and Hall, " Analytical Chemistry," Vol. 2, p. 604 (1930)]. Blank experiments with standard hydrochloric acid solutions were performed to check the reliability of the method in the presence of formic acid. The total chloride-ion concentration was determined by running 5-c.c. portions of the reaction mixture

into 50 c.c. of water, leaving the mixture overnight to complete the hydrolysis, and estimating chloride as above. Experiments in which accurately weighed quantities of *tert.*-butyl chloride were made up to a standard volume showed that this procedure gives a reliable estimate of the initial concentration of the halide. In the experiments in anhydrous formic acid, the *tert.*-butyl chloride was placed in a flask through which dry nitrogen was passed, and the medium was introduced through a glass tube directly from the freezing vessel by applying pressure to the latter. With the exception of this precaution to exclude moisture, the technique was the same as in the other experiments.

Calculations of First-order Constants.—The first-order rate constants are calculated from the integrated rate equation of a reversible reaction of the form $A \underset{k_2}{\overset{k_1}{\rightleftharpoons}} B + C$. If a is the concentration of *tert.*-butyl chloride initially, and x and x_∞ the concentrations of the products of reaction after t seconds and infinite time respectively, then

$$dx/dt = k_1(a - x) - k_2x^2$$

and at equilibrium

$$k_1(a - x_\infty) - k_2x^2_\infty = 0$$

wherefore

$$k_1 = \frac{x_\infty}{t(2a - x_\infty)} \log_e \left\{ \frac{ax_\infty + x(a - x_\infty)}{a(x_\infty - x)} \right\}$$

In Table II, a, x, and x_∞ are expressed as equivalent c.c. of $1{\cdot}004N/10$-ammonium thiocyanate (per 5 c.c. of reaction mixture); t is in secs., and k_1* is in sec.$^{-1}$. In one case only (col. 4, last section of table) the values of the "constants," calculated from the equation for a non-reversible unimolecular reaction, $k_1' = (1/t). \log_e \{a/(a - x)\}$, are recorded for comparison.

TABLE II.

t.	x.	10^4k_1.
"*Anhydrous formic acid.*"		
$a = 14{\cdot}00$, $x_\infty = 1{\cdot}00$.		
360	0·90	(2·25)
"10%" *Water in formic acid.*		
$a = 9{\cdot}00$, $x_\infty = 7{\cdot}58$.		
150	0·54	4·11
396	1·20	3·62
648	1·82	3·50
894	2·33	3·38
1134	2·85	3·40
1380	3·30	3·36
1626	3·75	3·39
1902	4·19	3·40
2388	4·90	3·47
3162	5·76	3·54
4176	6·49	3·60

t.	x.	10^4k_1.
"1%" *Water in formic acid.*		
$a = 8{\cdot}70$, $x_\infty = 2{\cdot}25$.		
156	0·51	3·91
312	0·95	3·90
558	1·53	4·12
822	1·85	3·98
"2%" *Water in formic acid.*		
$a = 8{\cdot}70$, $x_\infty = 3{\cdot}04$.		
198	0·63	3·83
336	0·99	3·69
624	1·65	3·68
882	2·06	3·60
1188	2·44	3·64
1518	2·71	3·74

t.	x.	10^4k_1.	$10^4k_1'$.
"*Kahlbaum*" *formic acid.*			
$a = 8{\cdot}22$, $x_\infty = 1{\cdot}52$.			
156	0·45	3·70	—
378	1·01	4·11	—
702	1·32	3·72	—
"5%" *Water in formic acid.*			
$a = 8{\cdot}62$, $x_\infty = 5{\cdot}00$.			
162	0·46	3·39	3·38
378	1·08	3·57	3·54
690	1·80	3·48	3·39
1158	2·97	3·97	3·65
1650	3·53	3·67	3·19
2256	4·19	3·84	2·95
2658	4·38	3·69	2·67
3054	4·55	3·66	2·46
3576	4·71	3·63	2·20

Reversibility of the Hydrolysis.—The reversible nature of the hydrolysis was confirmed when *tert.*-butyl alcohol was allowed to react with hydrogen chloride in aqueous formic acid solution. *tert.*-Butyl alcohol (0·0180 mol.) was made up to 100 c.c. at 15·0° with the medium obtained by mixing 90 c.c. of "Kahlbaum" formic acid and 10 c.c. of approximately 1·8N-hydrochloric acid. At intervals, 5-c.c. portions were withdrawn, and their chloride-ion contents determined by the method described for the kinetic experiments. The initial concentration of chloride ions was obtained as before by running 5 c.c. portions into water. The results are appended:

Time (hrs.)	0	2	19	20
[Cl⁻], (N)	0·179	0·150	0·154	0·149
% Cl as ions	100	83·8	86·6	83·2

It is to be noted that the conditions employed in this experiment are similar to those obtaining in the hydrolysis experiments in "10%" water in formic acid, and that the position of equilibrium is practically the same in each case (cf. Table I).

Reaction Products.—(a) *Olefin.* Reaction mixtures similar to those employed for the kinetic experiments were made up in a jar provided with an inlet and an outlet tube, the former reaching

* Some of the constants recorded are probably not very accurate owing to the short range over which measurements are possible before equilibrium is reached.

to the bottom. The latter was connected in series to a trap at 0°, a tube packed with powdered potash, two bubbling tubes containing known quantities of bromine in carbon tetrachloride the second of which was kept at 0°, and a trap containing aqueous potassium iodide. After a period of time sufficient for the attainment of equilibrium, a slow stream of nitrogen was blown through the inlet tube. A blank experiment with the medium substituted for the reaction mixture was conducted in exactly the same way for the same length of time. The olefin was estimated by titrating the remaining bromine with standard thiosulphate after addition of potassium iodide, and applying a small correction for the results of the blank experiment. The yield of olefin depended on the time of bubbling, owing, no doubt, partly to inefficient sweeping from the reaction mixture and partly to the effect on the equilibrium of removing one of the products of reaction. In " anhydrous " formic acid 10—15% of olefin was carried over after about 5 hours' bubbling. The yield decreased with increasing water content of the medium, and with 10% water in formic acid no olefin could be detected by this method. Attempts were made to determine accurately the amount of olefin formed in the reaction in " anhydrous " formic acid by adding a standard solution of bromine in carbon tetrachloride directly to the reaction mixture after equilibrium had been reached, shaking to extract the olefin into the tetrachloride layer, and estimating the halogen left after a standard period of time. In order to avoid the loss of olefin, the bromine–carbon tetrachloride was introduced through a tap-funnel into a partial vacuum created in the reaction vessel by cooling it in solid carbon dioxide–alcohol. The accuracy of the method, however, was vitiated by the fact that bromine reacts with formic acid. By applying a correction for the amount of halogen used up by the medium alone, determined in a separate experiment under similar conditions, it was found that the olefin estimation accounted for only about 60% of the chloride-ion concentration at equilibrium. In spite of the difficulties attending the experiment, we believe that this deficiency is real and is due to hydrolysis by traces of water and/or reaction with formic acid.

(b) tert.-*Butyl alcohol.* In order to obtain a more complete reaction, " 15% " water in formic acid was used as the medium of hydrolysis. *tert.*-Butyl chloride (20 c.c.) and the medium (100 c.c.) were shaken mechanically for 4 hours. The small upper layer was removed and shown to be unchanged *tert.*-butyl chloride (7 c.c.). The remainder was diluted with water (100 c.c.) and extracted with carbon tetrachloride (80 c.c.). The carbon tetrachloride was fractionated but no residue was obtained. The aqueous layer was neutralised with anhydrous sodium carbonate, saturated with sodium chloride, and fractionated over an 8-pear still-head. The fraction, b. p. 78·5°/735 mm. (6·5 c.c.), was repeatedly distilled from barium oxide. It finally had b. p. 82·5°; it solidified on cooling and was identified as *tert.*-butyl alcohol by direct comparison with an authentic specimen. In other similar experiments in various media ranging from Kahlbaum formic acid to " 15% " water in formic acid, the carbon tetrachloride used in the extraction was replaced by ether, and careful fractionation of the ethereal layer gave but a trace of residue which may have been *tert.*-butyl formate.

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251. *Mechanism of Substitution at a Saturated Carbon Atom. Part X. Hydrolysis of β-n-Octyl Bromide.*

By Edward D. Hughes and Uriel G. Shapiro.

The substitution and elimination reactions which occur simultaneously in the alkaline hydrolysis of β-*n*-octyl bromide are quite analogous to those relating to *iso*propyl halides (this vol., p. 1177). They have been analysed kinetically and given separate rate constants. A comparison with similar data for the hydrolysis of *iso*propyl bromide shows the effect on each of the constituent reactions of increasing the chain-length in a secondary halide. The rates of the unimolecular substitution and the bimolecular elimination are lower for the higher homologue, while the rate of the bimolecular substitution remains practically unchanged. An interpretation of these results is advanced. The data are utilised in the following paper on the stereo-orientation of substitutions in β-*n*-octyl bromide.

The experiments recorded in this paper were carried out with a three-fold object. First, it having been shown that the hydrolysis of *iso*propyl halides in aqueous-alkaline media

involves simultaneous unimolecular and bimolecular mechanisms, and that a change from this simple secondary alkyl system to the simplest primary and tertiary systems caused the disappearance of one mechanism or the other, it was desired to ascertain the effect on these constituent processes of passing to a higher homologue whilst maintaining the secondary character of the alkyl group. Secondly, the Walden inversion is being contemporaneously studied in these laboratories by the method of correlating the configurational effect of a substitution with its kinetics; and in this work β-*n*-octyl bromide has been chosen as a representative secondary halogeno-paraffin on account of the ease with which it can be obtained in optically active forms; therefore, of the secondary halides which we might have used in the pursuit of our first objective, we selected β-*n*-octyl bromide, so that our results would assist the parallel investigation. Thirdly, we desired to clear the ground for a prospective investigation into the mechanism of certain related elimination reactions, which we felt would be most profitably studied in the higher members of the alkyl series. Having summarised our results, we shall confine discussion to the first of these three aspects; their application in relation to the second is elucidated in the following paper, and their extension along the lines of the third is partly described in one of the last of the accompanying papers (this vol., p. 1277).

The solvent was "60%" aqueous ethyl alcohol, one of the two solvents used for the *iso*propyl halides. The temperature was 80·0°, and when the measurements at this temperature were complete it was decided not to extend them to other temperatures, because the rates of the constituent reactions of β-*n*-octyl bromide were not sufficiently different from the corresponding rates for *iso*propyl bromide to justify an attempted analysis on the basis of the Arrhenius equation.

As with *iso*propyl bromide, so also with β-*n*-octyl bromide, we obtained a total reaction of mixed order in the presence of moderate concentrations of alkali. The first-order reaction was isolated by the use of neutral or acid solutions and consisted essentially in substitution. The rate of the first-order reaction having been measured, it was possible to show that the remaining part of the total reaction which takes place in alkaline solution was of the second order. This second-order reaction, however, consisted partly of olefin elimination; and by suitable measurements of the octylene formed, it was possible to divide the total second-order rate between substitution and elimination.

The rate constants are shown, together with those for *iso*propyl bromide, in Table I. The first-order constant for *iso*propyl bromide was specially determined because, for a reason of experimental expediency, the "60%" ethyl alcohol solvent was made up in a different manner from that used in the previous work, and must have been of slightly different composition. The unimolecular hydrolysis of alkyl halides is very sensitive to changes in the composition of an aqueous medium, and in this case we found a rate constant about 8%* lower than we should have calculated from the results of the former work. The tabulated values for the bimolecular rate constants of *iso*propyl bromide are, however, calculated from the data obtained in the previous investigation, since such second-order rates are much less sensitive to small changes in the composition of the medium. The first-order constants are in sec.$^{-1}$, and the second-order constants in l./g.-mol.-sec.

TABLE I.

Rate constants of the constituent reactions of the hydrolysis of *iso*propyl bromide and β-*n*-octyl bromide in "60%" aqueous ethyl alcohol at 80·0°.

	$10^4k_1(S_N1)$.	$10^4k_2(S_N2)$.	$10^4k_2(E2)$.
*iso*Propyl bromide	0·908	3·56	5·01
β-*n*-Octyl bromide	0·519	3·55	4·40

Notwithstanding the kinetic analysis described, all the rate constants given in this table are composite. It is shown in another paper (p. 1277) that a small proportion of the reaction measured as S_N1 is due to olefin formation. More notable in the present connexion is the fact that a large proportion of the unimolecular substitution, S_N1, consists in ethoxylation accompanying the hydroxylation. We have not, however, attempted to determine the proportion of these products, because it is our view that the rate-determining process of all

* This corresponds to a difference of *ca.* 0·5% in the composition of the aqueous media.

of them is one and the same, *viz.*, the electrolytic dissociation of the alkyl halide. This is what the total first-order rate constant measures, so the figures recorded in the table under "S_N1" are quite the proper quantities to compare.

We note that the unimolecular rate for β-*n*-octyl bromide is the smaller, although the inductive effect of the additional *n*-amyl chain would have been expected to make it the larger. There is here a choice of explanations. "Steric hindrance" due to the extra chain could reduce the rate, *e.g.*, by diminishing solvation in the transition state, but it is possible that we have under observation an example of the effect postulated by Baker and Nathan (J., 1935, 1844) in which the electrons forming the C—H bonds of a methyl group participate in a tautomeric displacement which diminishes as the hydrogen atoms are replaced ($H—CH_2—CHMe—Br$ more easily ionised than $C_5H_{11}·CH_2·CHMe·Br$).

The bimolecular substitutions (S_N2) are also composite inasmuch as ethoxylation accompanies hydroxylation. It is difficult to determine accurately the proportion of each reaction, but experiments on the isolation of ethyl β-*n*-octyl ether from the products of hydrolysis of *d*-β-*n*-octyl bromide under conditions similar to those employed in our kinetic measurements (following paper) set a lower limit (*ca.* 20% of the total bimolecular substitution) to the ethoxylation. Since each reaction takes place in one stage, and through a distinct transition state, our rate constants represent the sums of those relating to the independent reactions.

The table shows that the rate constant for the bimolecular substitution (S_N2) is the same for β-*n*-octyl bromide as for *iso*propyl bromide. This occasions no surprise, as the effect of the additional alkyl chain is expected to be much smaller for bimolecular than for unimolecular substitution (cf. Hughes, Ingold, and Shapiro, J., 1936, 225).

The bimolecular elimination (E2) must again be composite, since the removal of a proton from the alkyl halide molecule may be assisted by a hydroxide ion or by an ethoxide ion in the aqueous-alcoholic solvent. There is, however, no way of distinguishing between these reactions. The table shows that the rate of olefin formation is lower for β-*n*-octyl than for *iso*propyl bromide. This could be explained on purely statistical grounds, for in the former only five β-hydrogen atoms are available for elimination as against six in the latter. The replacement of a β-hydrogen atom by an alkyl group must, however, introduce polar factors, which also contribute towards the result; but these are difficult to assess at present owing to lack of knowledge regarding the mutual influence of the β-hydrogen atoms. We may point out that the observed effect is in harmony with Hofmann's rule for olefin elimination (cf. Hanhart and Ingold, J., 1927, 997).

Experimental.

β-*n*-Octyl bromide was prepared by passing dry hydrogen bromide into β-*n*-octyl alcohol at 100°. The aqueous layer was removed at intervals, and the organic layer was again saturated with hydrogen bromide until the separation into layers ceased. The bromide was shaken with concentrated sulphuric acid to remove any unchanged alcohol, separated, dried in ethereal solution over anhydrous sodium carbonate, and distilled; b. p. 79°/17 mm., yield *ca.* 75%.

Rate Measurements.—We were handicapped in the selection of a suitable solvent by the insolubility of β-*n*-octyl bromide in water and of alkali hydroxides in non-hydroxylic media. Experiments in various mixtures of water with inert solvents such as acetone were frustrated either by a separation into two layers when the alkali was introduced in requisite amount or by the insolubility of the β-*n*-octyl bromide. We finally had to resort to aqueous ethyl-alcoholic media; and the mixture which gave the least proportion of β-*n*-octyl ether while still maintaining a homogeneous state at 80° contained 60% by volume of alcohol. Even in this medium the bromide is sparingly soluble at room temperature, and the reaction mixture had to be made up in a special way. Portions of 5 c.c. of a homogeneous solution of the halide (*ca.* $N/10$) in 80% aqueous ethyl alcohol (obtained by mixing 8 l. of lime-dried alcohol with 2 l. of water) were introduced into a number of thin-walled, glass tubes; 5 c.c. of 40% aqueous ethyl alcohol (4 l. of alcohol with 6 l. of water) were added to each, and the tubes were sealed, placed in the thermostat, kept at 80·00° ± 0·02° for known times, and then broken under 100 c.c. of absolute alcohol. In the experiments in alkaline solution the 5 c.c. of 40% aqueous ethyl alcohol were replaced by

an equal volume of *ca.* 2*N*-potassium hydroxide in 40% alcohol. The reactions were followed by estimating bromide ion in the neutralised or faintly acid solution by titration with 0·025*N*-silver nitrate in the presence of eosin. Similar experiments were carried out with *iso*propyl bromide in initially neutral solution.

Estimation of Olefin.—The sealed tube was broken under carbon tetrachloride (150 c.c.), and the organic layer was washed with dilute sulphuric acid and water; 10 c.c. of a solution of bromine in carbon tetrachloride were added, the mixture was left for 30 minutes, and the remaining bromine estimated by titration with standard thiosulphate after addition of potassium iodide. A blank experiment was run in the same way with 10 c.c. of the medium, and the result of this experiment was taken as the bromine equivalent when no olefin was present.

Reaction Products.—The isolation of the reaction products under conditions similar to those obtaining in our kinetic measurements is described in Part XI (following paper). Octylene, β-*n*-octyl alcohol, and ethyl β-*n*-octyl ether were isolated both in acid and in alkaline hydrolysis. A quantitative separation is impracticable, but the yield of olefin from the alkaline hydrolysis (47 mols. %) is in satisfactory agreement with our estimations, and the isolation of ethyl β-*n*-octyl ether gives a minimum figure (7 mols. %) for the ethoxylation.

The First-order Reaction.—The results of a typical kinetic experiment are recorded in Table II; k_1 is the first-order rate constant calculated from the formula $k_1 = (1/t) \cdot \log_e\{a/(a - x)\}$, where a is the initial concentration of β-*n*-octyl bromide and x the decrease in concentration; a was determined by measuring the asymptotic value of x after long intervals.

Table II.

Initially, [β-*n*-$C_8H_{17}Br$] ~ $N/20$ and [NaOH] = 0. [β-*n*-$C_8H_{17}Br$] expressed in c.c. of 0·025*N*-$AgNO_3$ per 10 c.c. of reaction mixture; k_1 is in hours^{-1}.

t (hrs.)	0·00	0·65	1·00	1·71	2·40	3·90	5·40	6·90	8·65
[β-*n*-$C_8H_{17}Br$]	20·55	18·30	16·90	14·90	13·20	9·90	7·60	5·60	4·00
10^3k_1	—	178	195	188	184	187	184	188	189

The Total Second-order Reaction.—The method of calculating the second-order constant from observations of the total reaction is the same as that described for the *iso*propyl halides (J., 1936, 225; this vol., p. 1177). In Table III, k_2 is the bimolecular "constant" calculated from the formula

$$K_2 = \frac{1}{t(b - a)} \cdot \log_e \frac{b(a - x)}{a(b - x)}$$

where a and b are the initial concentrations of β-*n*-octyl bromide and sodium hydroxide respectively, and x is the decrease in concentration after time t. "Corr. k_1" = $k_1(b - x)$ signifies the correction (due to the simultaneous unimolecular reaction, rate constant = k_1) which must be applied to K_2 in order to deduce the true second-order constant k_2. K_2 and k_2 are in l./g.-mol.-hour.

Table III.

Initially, [β-*n*-$C_8H_{17}Br$] ~ 0·05*N* and [NaOH] = 0·8*N*. [β-*n*-$C_8H_{17}Br$] and [NaOH] expressed in c.c. of 0·025*N*-$AgNO_3$ per 10 c.c. of solution.

t (hrs.).	[β-*n*-$C_8H_{17}Br$].	[NaOH].	K_2.	"Corr. k_1."	k_2.	t (hrs.).	[β-*n*-$C_8H_{17}Br$].	[NaOH].	K_2.	"Corr. k_1."	k_2.
0·00	20·75	321·00	—	—	—	0·250	11·20	311·45	3·13	0·24	2·89
0·050	18·45	318·60	2·96	0·23	2·73	0·300	9·90	310·15	3·14	0·24	2·90
0·100	16·20	316·45	3·12	0·24	2·88	0·367	8·50	308·75	3·10	0·24	2·86
0·133	15·00	315·25	3·07	0·24	2·83	0·483	6·45	306·70	3·10	0·24	2·86
0·160	13·80	314·05	3·09	0·24	2·85	0·633	4·70	304·95	3·02	0·25	2·77
0·200	12·70	312·95	3·11	0·24	2·87	0·750	3·40	303·65	3·32	0·25	3·06
										Average	2·86

The Separate Second-order Reactions.—In the following table, col. 1 gives the percentage of olefin formed by the second-order process [obtained by applying a correction (0·7%) to the total olefin estimation to account for the small amount which is produced by the simultaneous first-order process]; col. 2 gives the percentage of products formed by the total first-order reaction calculated from the relationship given in Part VI, and col. 3 gives the figures, obtained by difference, for the products formed by the bimolecular substitutions. Cols. 4 and 5 contain the factors which, when multiplied into the total second-order rate constant (Table III), give the rate

constants (recorded in cols. 6 and 7 in l./g.-mol.-hour) for the two separate bimolecular reactions.

E2 (%).	S_N1 + E1 (%).	S_N2 (%).	$\frac{S_N2}{S_N2 + E2}$.	$\frac{E2}{S_N2 + E2}$.	$k_2(S_N2)$.	k_2(E2).
51·1	7·2	41·7	0·448	0·552	1·28	1·58

We wish to express our gratitude to Professor C. K. Ingold, F.R.S., for his interest in the work described in this and the previous papers.

UNIVERSITY COLLEGE, LONDON. [*Received, April 24th*, 1937.]

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252. *Reaction Kinetics and the Walden Inversion. Part I. Homogeneous Hydrolysis and Alcoholysis of β-n-Octyl Halides.*

By EDWARD D. HUGHES, CHRISTOPHER K. INGOLD, and STANDISH MASTERMAN.

The mechanism of many substitutions having in past papers been related to structure through the examination of kinetics, it was decided to study the spatial orientation of substitution under kinetically defined conditions, thus to elucidate the rules of the Walden inversion in a more rational manner than has hitherto been attempted. The replacement of Hal by OR being taken as the starting point, data are here given for this substitution in the case in which the only substituents at the asymmetric centre, apart from the replaceable group, are hydrogen and alkyl groups: the example studied is the hydroxylation or ethoxylation of β-*n*-octyl chloride or bromide.

In order to interpret the results it is necessary to know the maximal rotatory powers of the factors and products, and the relation of configuration to sign of rotation; also the kinetics of substitution, and the specific rates of the constituent reactions. Evidence on these points is summarised. With this aid, we isolate the bi- and uni-molecular mechanisms, and, from observations of the optical effect of substitution under kinetically definite conditions, determine the stereochemical effect associated with each mechanism. We find that bimolecular substitution leads to inversion of configuration without associated racemisation, whilst unimolecular substitution causes inversion with considerable accompanying racemisation. Quantitative particulars are given.

IN a series of papers entitled "Mechanism of Substitution at a Saturated Carbon Atom" we have attempted to bring mechanism as disclosed by reaction kinetics into intelligible relation with the structures of reactants and the physical conditions of reaction. For a general statement of the nature of the connexion revealed, it will be sufficient to refer to a summarising paper published early in 1935, although the principles there laid down have received more extensive illustration since. In this paper (Hughes and Ingold, J., 1935, 244) the steric orientation of substitution was briefly discussed; but this aspect of substitution—the question of what determines the occurrence or non-occurrence of the Walden inversion—seemed so especially important, and to involve so many obscure points, that it was decided to make it the subject of a special experimental campaign, some of the first results of which are now presented. In Parts I—V we report observations and the immediate conclusions to be derived from them, and in Part VI we outline in a more general manner the position of the subject as it appears to us at present.

This paper deals with the steric orientation of the hydrolysis and alcoholysis of β-*n*-octyl halides. The first point to be considered is the connexion between the configuration and sign of optical rotation of β-*n*-octyl alcohol in relation to the halides. As to this matter, Houssa, Kenyon, and Phillips (J., 1929, 1700) have adduced the following argument. Of the four reactions one (if not three) must involve inversion; the only one which could do so is the extrusion of the sulphonate group by the attack of acetate ions in ethyl alcohol (I), since this is the only reaction of the four which exchanges a bond attached to the asymmetric carbon atom. It is now assumed that an attack by chloride ions in ethyl

alcohol on the organic sulphonate would proceed by a similar mechanism, and, like the attack by acetate ions, would be accompanied by an inversion of configuration. The

$$\begin{array}{ccc} d\text{-}C_8H_{17}\cdot OH \xrightarrow{R\cdot SOCl} d\text{-}C_8H_{17}\cdot O\cdot SOR & & l\text{-}C_8H_{17}\cdot OH \\ \quad\quad\quad\quad\quad\quad\quad\quad \downarrow O & & \downarrow Ac_2O \\ d\text{-}C_8H_{17}\cdot O\cdot SO_2R & \xrightarrow[{[OAc]^-}]{} & l\text{-}C_8H_{17}\cdot OAc \end{array} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (I)$$

product of the reaction has a rotation of sign opposite to that of the alcohol from which the sulphonate was prepared, and, from the assumption that configuration is inverted in

$$d\text{-}C_8H_{17}\cdot O\cdot SO_2R \xrightarrow[Cl^-]{} l\text{-}C_8H_{17}Cl \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (II)$$

reaction (II), it follows that a β-*n*-octyl alcohol and chloride of like sign of rotation have corresponding configurations. The crux of this argument is the unproved assumption of an analogy of behaviour between acetate ions and halide ions; but, if we take a second step of the same kind and assume similarity of behaviour between the octyl sulphonate and the corresponding halides, we arrive at a conclusion which is undeniably correct: the

$$d\text{-}C_8H_{17}\cdot I \xrightarrow[I^-]{} l\text{-}C_8H_{17}\cdot I \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (III)$$

substitution has been proved by the radioactive indicator method essentially to involve inversion (Hughes, Juliusburger, Masterman, Topley, and Weiss, J., 1935, 1525). Furthermore, although the generalisations which have been proposed by Olson, by Polanyi, and by Hughes and Ingold concerning the occurrence of inversion are not quite identical, they all agree in placing reactions (I), (II), and (III) in the same case and predicting inversion for them all; and, as this is the result to which Houssa, Kenyon, and Phillips's argument leads, our confidence in the correctness of their inference is strengthened.

The same authors extended their conclusion to embrace β-*n*-octyl bromide and iodide *on the basis of the following argument, also of a kind which we regard as convincing. On* treatment with hydrogen chloride the alcohol gives a chloride with a rotation opposite in sign to that of the alcohol; therefore, by the previous demonstration, this reaction is accompanied by inversion. It is accordingly assumed that the reactions of the alcohol with hydrogen bromide and hydrogen iodide must involve inversion; and since the β-*n*-octyl bromide and iodide thus produced each have a rotation opposite in sign to that of the alcohol, it follows that the relation of rotation to configuration is the same for the three halides. Our results provide a second argument. When the chloride is alcoholised with sodium ethoxide in anhydrous ethyl alcohol, a β-*n*-octyl ethyl ether is formed, the sign of the rotation of which is opposite to that of the chloride:

$$d\text{-}C_8H_{17}\cdot Cl \xrightarrow[OEt^-]{} l\text{-}C_8H_{17}\cdot OEt \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (IV)$$

It is known that a β-*n*-octyl alcohol and a β-*n*-octyl ethyl ether which have rotations of the same sign have the same configuration, because there is no change in the sign of rotation when the alcohol is etherified through its potassium derivative (Kenyon and McNicol, J., 1923, **123**, 14), a process which must necessarily retain the original configuration. It follows that the alcoholysis of the chloride involves inversion, and this is just what we should expect since reaction (IV) belongs to the same class of substitution as do (I), (II), and (III). It may safely be assumed that a corresponding alcoholysis of the bromide would involve inversion, and since the experiment leads to an ether having a rotation opposite in sign to that of the bromide, it follows that the relation of rotation to configuration is similar for the chloride and bromide. The general conclusion is that when β-*n*-octyl alcohol, its ethyl ether and any of the three halides have rotations of the same sign their configurations correspond.

With this basis for the translation of observations on rotatory power into terms of molecular configuration, we have set out to discover the changes of optical rotation which accompany the hydrolysis of β-*n*-octyl halides under various conditions; we have worked

mainly with the bromide. In an accompanying paper (Hughes and Shapiro, this vol., p. 1192) it is shown that β-*n*-octyl bromide undergoes hydrolysis by both the bimolecular and the unimolecular mechanism :

$$\bar{O}H + C_8H_{17}{\cdot}Br \longrightarrow C_8H_{17}{\cdot}OH + \bar{B}r \quad . \; . \; . \; . \; . \; . \quad (S_N2)$$

$$\left.\begin{array}{l} C_8H_{17}{\cdot}Br \longrightarrow C_8H_{17}^{+} \quad + \bar{B}r \text{ (slow)} \\ \bar{O}H + C_8H_{17}^{+} \longrightarrow C_8H_{17}{\cdot}OH \text{ (fast)} \end{array}\right\} \quad . \; . \; . \quad (S_N1)$$

In general these reactions occur simultaneously, but it is possible to choose conditions such that each is more or less completely isolated from the other. There are additional simultaneous reactions leading to the production of octylene, but from our present point of view these processes simply put some of the material out of action, octylene being necessarily optically inactive. We made some observations on the kinetics of the reactions, but we wished to be able to make use of the more comprehensive kinetic data provided by Hughes and Shapiro, and on this account used the same solvent as they did, *viz.*, " 60% " aqueous ethyl alcohol : in this solvent ethyl octyl ether is formed as well as octyl alcohol. Therefore we had to consider the changes of optical activity associated, not only with the hydrolysis formulated above, but also with the corresponding alcoholysis.

Our method was to remove the octylene in the form of its dibromide, then to isolate the octyl alcohol and ethyl octyl ether together, and finally to separate these two substances by converting the former into its hydrogen phthalate. All these isolation processes take place without detectable enantiomeric change. It was unnecessary to hydrolyse the hydrogen phthalate, since the relation of its rotatory power to that of the octyl alcohol obtainable from it is known (" Organic Syntheses," **6**, 68).

Optically pure β-*n*-octyl alcohol has the rotation $[\alpha]_D^{17°} \pm 9{\cdot}9°$. We have used specimens having various rotations above $\pm$ 9°, because we needed only easily measurable rotations, not optical purity, and because the halides prepared from the alcohol would in any case be optically impure. As this last statement is contrary to a suggestion made by Pickard and Kenyon (J., 1911, **99**, 45; *Ber.*, 1912, **45**, 1592), we give the evidence. We also calculate the approximate rotation of optically pure bromide, because this datum enables us to express our results in a simple form.

The recorded rotatory powers of the halides prepared by various methods from the optically active alcohols are noted in Table I. In those cases in which the alcohol employed has not been quite fully resolved, the observed rotations of the halides are corrected to correspond to optically pure alcohol. It will be seen that in spite of the practical equality of the dextro- and lævo-rotations recorded for the halides prepared by Pickard and Kenyon using the hydrogen halides as reagents, considerably higher rotations than theirs have been obtained either with the same reagents or with others. It would appear that all the reagents hitherto employed are liable to bring about some degree of racemisation.

TABLE I.

Reagent.	Temp.*	$[\alpha]_D$.		Ref.	Reagent.	Temp.*	$[\alpha]_D$.		Ref.
Chloride.					*Bromide.*				
HCl	17°	+20·40°	−20·44°	1	HBr	17°	+27·53°	−27·47°	1
$SOCl_2$	Room	+33·5	—	2†	HBr	Room	+14·4	—	2†
$SOCl_2$, Pyridine ...	20	+33·7	—	3	$SOBr_2$, Pyridine ...	16·5	—	−26·1	3
$SOCl_2$	20	+35·8	—	4	HBr	20	+32·5	−26·9	5†
					Iodide.				
$SOCl_2$, Pyridine ...	20	+32·2	—	5†	HI	17	+39·83	−40·56	1

* Temperature at which rotations were measured.
† Rotations corrected to correspond to optically pure alcohol.

References.—(1) Pickard and Kenyon (*loc. cit.*). (2) Levene and Mikeska (*J. Biol. Chem.*, 1924, **59**, 473). (3) McKenzie and Tudhope (*ibid.*, 1924, **62**, 551). (4) Houssa, Kenyon, and Phillips (*loc. cit.*). (5) This paper. *Note.*—Other rotations at λ5461 for the chloride produced by various reagents are recorded by Houssa and Phillips (J., 1932, **108**).

We can calculate an approximate value for the specific rotation of optically pure β-*n*-octyl bromide, the halide with which we are mainly concerned, in the following way. The

highest recorded specific rotation is our value $[\alpha]_D^{20^\circ}$ 32·5°; this is a lower limit. An upper limit follows from our observation that the same specimen of bromide could be hydrolysed back to an alcohol having 85·2% of the activity of the alcohol from which the bromide was originally made. This limit, 32·5°/0·852 = 38·1°, is obtained by supposing that the loss of enantiomeric identity occurs exclusively in the formation of the bromide, the hydrolysis occurring entirely without racemisation. Now this last supposition is untrue, but there are reasons (Part VI) for the belief that it would be very nearly true if the hydrolysis were to proceed exclusively by mechanism S_N2. On the other hand, the results recorded in this paper prove that considerable racemisation accompanies the hydrolysis of β-*n*-octyl bromide by mechanism S_N1. The particular hydrolysis which forms the basis of this computation occurs mainly by mechanism S_N2, but also partly by mechanism S_N1, and we can calculate the ratio $S_N2 : S_N1$ either from the kinetic measurements which we have made, or, more accurately, from data provided by Hughes and Shapiro (*loc. cit.*). The ratio is $S_N2 : S_N1$ = 88 : 12. Furthermore we show that, in the solvent used, the enantiomeric purity of material which is hydrolysed by the S_N1 process drops to 35% of its original value. Hence, if we assume no racemisation in the S_N2 reaction, the retention of enantiomeric purity in the total hydrolysis should amount to 92·2%, and the retention in the formation of the bromide to 85·2/0·922 = 92·4%. On this basis the specific rotation of the optically pure bromide would be $[\alpha]_D$ 35·1°. This figure is a closer upper limit, and we have another experiment which proves that it is still slightly too high. Using anhydrous ethyl alcohol as solvent, we have converted β-*n*-octyl bromide into an ethyl octyl ether the rotatory power of which, if calculated to correspond to a bromide having $[\alpha]_D$ 35·1°, comes out 3·8% greater than the rotatory power, $[\alpha]_D^{20^\circ}$ 17·1°, of ether prepared directly from optically pure β-*n*-octyl alcohol by a method which cannot involve racemisation. The best value we can obtain for the rotatory power of the bromide is thus 35·1°/1·038 = 33·8°. This assumes that our etherification of the bromide proceeded without racemisation, as substantially it must have done. We etherified the chloride by exactly the same method, and, supposing that this reaction likewise went without racemisation, calculated the specific rotation of optically pure chloride to be $[\alpha]_D^{20^\circ}$ 38·3°. The first of these figures is used below in estimating percentages of retention of enantiomeric purity, and any uncertainty attaching to the value cannot be large enough to affect the principal conclusions.

The bromide has been hydrolysed in boiling "60%" aqueous ethyl alcohol, *i.e.*, a mixture made from 60 vols. of anhydrous alcohol and 40 vols. of water, under the following conditions: (1) In the presence of potassium hydroxide in concentration which decreases during the reaction but always remains of the order 1·0*N*; in these circumstances both the hydrolysis and the alcoholysis are mainly bimolecular, but are also partly unimolecular. (2) In the absence of any added substance, the solution being neutral at the commencement of reaction but acid with hydrobromic acid during its progress; both the hydrolysis and alcoholysis are now unimolecular.

The bromide and chloride have also been alcoholysed by means of sodium ethoxide in anhydrous ethyl alcohol at the boiling points of the solutions. In these conditions, there is, of course, no hydrolysis; and the alcoholysis must be practically exclusively bimolecular as the action of the pure solvent on the halides is relatively very slow.

Results and Conclusions.

The upper part of Table II summarises the results relating to hydrolysis. The conditions of the various experiments are noted in the first few cols., the headings of which are self-explanatory. The next two cols. give the percentages in which hydrolysis proceeds by the second- and first-order reactions, the figures being calculated from the kinetic data. The next three cols. record respectively the specific rotation of the bromide used, that of the alcohol obtained, and that which the alcohol would have had if prepared from optically pure bromide. In the penultimate column this rotation is expressed as a percentage of the specific rotation of optically pure alcohol; the figures therefore represent the percentage extent to which enantiomeric purity is retained in the hydrolytic substitution, and their differences from 100 are percentages of racemisation. In the last col. a correction is made

for the fact that some of the β-*n*-octyl bromide becomes racemised before substitution owing to attack by the bromide ions liberated in the course of reaction; the figures thus represent the percentages in which optical purity would be retained if the octyl bromide underwent no racemisation prior to substitution. The correction is based on a study of the kinetics by polarimetric as well as analytical methods. The third row of figures, which relate to a purely bimolecular hydrolysis, are calculated from the experimental data in the first two rows. The lower part of the table contains the results for alcoholysis.

TABLE II.

Hydrolysis of β-n-Octyl Bromide.

Solvent.	Concn. of KOH, HBr, etc. (*N*). Initial. Final.	Proportions of simultaneous reactions. S_N2 (%).	S_N1 (%).	Bromide, $[\alpha]_D^{20°}$.	Alcohol, $[\alpha]_D^{20°}$. Obs.	Corr. to pure halide.	Retention of optical purity (%).* Uncorr.	Corr.
60% Aqueous EtOH	1·23—0·91 KOH	88	12	+29·78°	− 7·73°	− 8·78°	− 89	− 93
	0·00—0·31 HBr	0	100	−24·54	+ 2·54	+ 3·46	− 35	− 66
	(Calculated)	100	0	+33·80	− 9·50	− 9·50	− 96	− 96

Ethyl Alcoholysis of β-n-Octyl Halides.

				Halide, $[\alpha]_D^{20°}$.	Ether, $[\alpha]_D^{20°}$. Obs.	Corr.		
β-n-Octyl bromide.								
60% Aqueous EtOH	1·23—0·91 KOH	95	5	−30·28	+13·93	+15·53	− 91	− 95
	0·00—0·31 HBr	0	100	−24·54	+ 4·90	+ 6·74	− 39	− 74
	(Calculated)	100	0	+33·80	−15·98	−15·98	− 94	− 96
EtOH	2·18—1·67 NaOEt	100	0	−24·54	+12·41	+17·10	−100	−100
β-n-Octyl chloride.								
EtOH	2·18—1·67 NaOEt	100	0	+29·79	−13·30	−17·10	−100	−100

* The negative sign signifies that configuration is inverted.

It will be observed that the common result of all these reactions—bimolecular and unimolecular, the alcoholyses as well as the hydrolyses—is to give a product having an inverted sign of rotation, and this, as we have seen, means an inverted configuration. On the other hand, the bimolecular and unimolecular reactions are distinguished in that the latter involve much larger amounts of racemisation than the former. These results will be considered along with other data in Part VI.

EXPERIMENTAL.

Optically Active β-n-*Octyl Halides.*—β-*n*-Octyl alcohol was treated at 60—70° with dry hydrogen bromide until two layers were formed and the lower ceased to increase. The product was extracted with ether, washed successively with sodium hydrogen sulphite, sodium carbonate and water, dried with sodium sulphate, and distilled. The distilled material was shaken with concentrated sulphuric acid, left in ethereal solution in contact with anhydrous sodium carbonate, and again distilled. Octyl alcohol with $[\alpha]_D^{20°}$ − 9·07° and + 9·17° gave in separate experiments bromide with $[\alpha]_D^{20°}$ + 29·78° and − 24·54° respectively (Found: C, 49·6; H, 8·5; Br, 42·2. Calc.: C, 49·7; H, 8·8; Br, 41·5%). β-*n*-Octyl chloride was prepared as described by McKenzie and Tudhope (*loc. cit.*); alcohol with $[\alpha]_D^{20°}$ − 9·15° gave chloride with $[\alpha]_D^{20°}$ + 29·79°.

Alkaline Hydrolysis of Bromide.—The bromide (30 g.) was hydrolysed for 5 hours under the conditions specified in Table II. The product was diluted with water (5 l.), acidified with sulphuric acid, and extracted with light petroleum. After removal of most of the solvent, bromine was added at 0° until the liquid remained faintly coloured, and the octyl alcohol and ethyl octyl ether were separated by distillation from the bulk of the dibromo-octane (17·5 g., b. p. 110°/14 mm.). The mixture of alcohol and ether (6 g.) was heated with phthalic anhydride (6 g.) for 12 hours at 110—115°, and the product digested with 2*N*-aqueous sodium carbonate (400 c.c.) and extracted with ether. The extract yielded ethyl β-*n*-octyl ether, b. p. 68°/18 mm. (yield 1·6 g. after a further non-ebullient distillation) (Found: C, 76·0; H, 13·9. Calc.: 75·9; H, 13·9%), and dibromo-octane (2·2 g., b. p. 114°/16 mm.). The alkaline solution was freed from ether by means of a current of air, acidified, and extracted with chloroform; the residue from the chloroform extract was evaporated with additions of light petroleum,

and the β-*n*-octyl hydrogen phthalate was crystallised (1·35 g., $[\alpha]_D^{20°}$ − 42·8°) in the presence of this solvent. A further small quantity (0·04 g., $[\alpha]_D^{20°}$ − 19·5°) of the hydrogen phthalate (Found : C, 69·5; H, 8·0. Calc. : C, 69·1; H, 7·9%) was obtained by cooling the petroleum filtrate in solid carbon dioxide. The rotations were taken in dry ethyl alcohol. The two specimens of hydrogen phthalate differed in rotation because the crystallisation effects a partial resolution; the rotation of the total phthalate is, of course, used in calculating the rotation of the equivalent β-*n*-octyl alcohol. The losses in the crystallisation of the hydrogen phthalate are insignificant, and in these isolation processes generally the losses of material occur practically exclusively in the extraction and distillations of liquids; hence they are not optically selective.

Acid Hydrolysis of Bromide.—The bromide (15 g.) was hydrolysed for 3 days under the conditions defined for acid hydrolysis in Table II. The product was worked up as described in the previous paragraph, except that it was unnecessary to add acid after pouring into water, and that the hydrogen phthalate of the alcohol was not collected in two parts, but altogether (8·87 g., $[\alpha]_D^{20°}$ + 12·23°) at the temperature of a carbon dioxide freezing mixture. The other products were octyl ether (0·65 g.) (Found : C, 74·2; H, 13·6%) and dibromo-octane (0·1 g.).

Alcoholysis of Bromide and Chloride.—The bromide (20 g.) was alcoholysed with a solution of sodium ethoxide in anhydrous ethyl alcohol for 2 hours, the other conditions being as specified in Table II. The products, worked up as already described except that the treatment with phthalic anhydride was omitted, were dibromo-octane (17 g.) and ethyl octyl ether (1·2 g.). The chloride (15 g.), similarly treated, also gave dibromo-octane (11·65 g.) and the ether (1·45 g.) (Found : C, 75·9; H, 14·0%). The yields of liquid products quoted here and throughout are those of analysis samples or of fully rectified material, usually thrice distilled.

Note.—The preceding measurements with optically active material were carried out before the kinetic data by Hughes and Shapiro had been completed, and it was therefore necessary to conduct approximate kinetic measurements in order to establish appropriate conditions in which to investigate the optical effects. These measurements were made at the b. p.'s of the solutions, the temperatures used in the optical investigations; but as these temperatures are very close to the temperature 80·0° used by Hughes and Shapiro it is unnecessary to publish the results, which only serve to confirm the more accurate data obtained by these authors. We omit also all description of the methods of calculation, since these were quite similar to those illustrated in Part III.

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253. *Reaction Kinetics and the Walden Inversion. Part II. Homogeneous Hydrolysis, Alcoholysis, and Ammonolysis of α-Phenylethyl Halides.*

By EDWARD D. HUGHES, CHRISTOPHER K. INGOLD, and ALAN D. SCOTT.

The next case to be taken up in the kinetics-controlled stereochemical study of the replacement of Hal by OR is that in which, besides hydrogen and alkyl, an aryl group is attached to the asymmetric atom : we study now the hydroxylation, methoxylation or ethoxylation (also amination) of α-phenylethyl chloride and bromide.

It was necessary, as in the previous case, to fix maximal rotations and the relation of configuration to sign of rotation. Kinetic measurements showed that unimolecular hydroxylation was the only realisable hydroxylation, whereas both uni- and bi-molecular methoxylation and ethoxylation occurred : the rates of the separate and the simultaneous reactions were determined. For the investigation of the optical effect of substitution, the simultaneous reactions could be isolated (in part by calculation), so that again it was possible to determine the stereochemical effect associated with each mechanism. It was found that bimolecular substitution leads to inversion with little if any racemisation, whilst unimolecular substitution produces a predominating inversion with extensive, sometimes nearly complete, racemisation. The amount of racemisation accompanying unimolecular hydroxylation was increased when the water in the medium was replaced by acetone. Quantitative particulars are given.

This paper records a study of steric orientation in nucleophilic replacements of X in the system CHMePh·X. The reactions which we have investigated are the hydrolysis, methyl alcoholysis, ethyl alcoholysis, and ammonolysis of α-phenylethyl chloride, and the hydrolysis of the bromide.

We have first to consider the relation of sign of rotation to configuration amongst α-phenylethyl compounds, and the central part of this problem is the establishment of such a relation for the alcohol and the chloride. Concerning this point, Kenyon, Phillips, and Taylor (J., 1933, 173) have adduced a line of reasoning which, whilst superficially similar to that which Houssa, Kenyon, and Phillips applied with success to β-*n*-octyl alcohol and its chloride, is actually less convincing; it can, however, be made part of the basis of a conclusive argument. The inversion involved in the sequence

$$
\begin{array}{ccccc}
l\text{-CHMePh·O·SOR} & \xleftarrow{\text{R·SOCl}} & l\text{-CHMePh·OH} & \xrightarrow{\text{Ac}_2\text{O}} & l\text{-CHMePh·OAc} \\
\downarrow O & & & & \\
l\text{-CHMePh·O·SO}_2\text{R} & \xrightarrow{\text{HOAc}} & d\text{-CHMePh·OAc} & & \quad . \quad . \quad . \quad . \quad (\text{I})
\end{array}
$$

can occur only in reaction (I), since this is the only reaction in which a bond of the asymmetric carbon atom is exchanged. Kenyon, Phillips, and Taylor assume that this process is paralleled as to mechanism by reaction (II), which therefore may be presumed also to involve inversion:

$$l\text{-CHMePh·O·SO}_2\text{R} \xrightarrow{\bar{\text{Cl}}} d\text{-CHMePh·Cl} \quad . \quad . \quad . \quad . \quad . \quad (\text{II})$$

Since the rotation of the chloride thus formed is opposite in sign to that of the original alcohol, it follows that an alcohol and chloride with rotations of like sign have similar configurations. The result is right, as we shall see, but the keystone of this argument is frail in that there is no evidence of the assumed identity of mechanism. One would be inclined *a priori* to presume the contrary. No acetate ions were added in the form of a metallic acetate in reaction (I), which is simply a decomposition of the sulphonate with the acetic acid solvent; it probably proceeds by a unimolecular mechanism (S_N1), kinetically dependent on the ionisation of the sulphonate. On the other hand, the reaction with the added chloride ions (II) may well be ordinary bimolecular replacement (S_N2).

We can, however, complete the demonstration in either of two ways, which both involve the use of other data. One method is as follows. Reaction (II) is a nucleophilic substitution which must be either unimolecular or bimolecular. If it is unimolecular, we may be sure that reaction (I) will be also; in this case, then, the reactions are analogous, so that the original conclusion holds. If, in the alternative, reaction (II) is bimolecular, then the proper analogy is with (III), which has been proved by the use of radioactive bromine to involve inversion (Hughes, Juliusburger, Scott, Topley, and Weiss, J., 1936, 1173):

$$l\text{-CHMePh·Br} \xrightarrow{\bar{\text{Br}}} d\text{-CHMePh·Br} \quad . \quad . \quad . \quad . \quad . \quad (\text{III})$$

Therefore in any case reaction (II) involves inversion, and the original conclusion stands.

The second argument depends on the demonstration given in this paper that for α-phenylethyl compounds unimolecular and bimolecular nucleophilic substitutions have the same type of steric orientation. Actually we shall show that the dominant steric orientation in this series is always inversion, but all that it is necessary to accept at this stage is what follows immediately from the experimental results, *viz.*, the *similarity* of orientation. Hence, without considering mechanism, we may be sure that reaction (II) involves inversion because we know that reactions (I) and (III) do so. This also establishes the original conclusion.

Kenyon, Phillips, and Taylor observed that much racemisation accompanied both the reactions (I) and (II), and we shall show that in the α-phenylethyl series a large amount of racemisation is characteristic of unimolecular nucleophilic substitutions. This is consistent with the view that reaction (I) occurs by the unimolecular mechanism. As to reaction (II) there are two possibilities: either it is unimolecular, racemisation being then a normal

accompaniment, or it is bimolecular and is succeeded by a racemising halogen exchange of the type of reaction (III).

We have now to extend the argument concerning the connexion of rotation with configuration to the other α-phenylethyl compounds which we have employed. Pickard and Kenyon have shown (J., 1911, **99**, 45), and we have confirmed, that on treatment with hydrogen chloride α-phenylethyl alcohol gives a chloride with an inverted sign of rotation; it follows from the foregoing that this reaction inverts configuration. We therefore assume an inversion of configuration in the reaction of hydrogen bromide with the alcohol. Contrary to Holmberg (*Ber.*, 1912, **45**, 997) who obtained a completely racemic bromide, we find that this reaction gives a bromide with an inverted sign of rotation.* It follows that the relation of rotation to configuration is similar for the chloride and bromide. A confirmatory observation is that when either the chloride or the bromide is hydrolysed by water the resulting alcohol has an inverted sign of rotation.

The alkylation of an alcohol through its sodium salt cannot involve a Walden inversion. When α-phenylethyl alcohol is methylated or ethylated by this method the methyl or ethyl ether has a rotation of the same sign as that of the original alcohol. It follows that the alcohol and its ethers with like signs of rotation have like configurations.

When α-phenylethyl chloride is treated with sodium methoxide in methyl-alcoholic solution a bimolecular substitution occurs. The methyl ether formed has an inverted sign of rotation, and therefore, by the preceding argument, an inverted configuration. A similar result follows when the reagent is sodium ethoxide in ethyl-alcoholic solution, and the inference is the same. It also follows directly from the results quoted later that the predominating stereo-orientation in unimolecular hydrolysis and in unimolecular and bimolecular methyl and ethyl alcoholysis is the same, *viz.*, inversion. We may assume that the same will be true for ammonolysis even though the kinetics are not experimentally established. The amine produced has an inverted sign of rotation. It follows that the chloride and amine when in the same configuration have rotations of the same sign.

Summarising, we find that when α-phenylethyl chloride, bromide, alcohol, methyl ether, ethyl ether, and α-phenylethylamine have rotations of the same sign their configurations are similar.

These preliminary questions settled, we may turn to the main part of the research, the object of which was to determine the changes of optical activity accompanying substitutions under conditions of defined reaction kinetics.

We have examined the hydrolysis of optically active α-phenylethyl chloride by the following reagents: (1) Water.—Two liquid phases were present, the aqueous layer, initially neutral, becoming acid with hydrochloric acid during the progress of hydrolysis. (2) Aqueous potassium hydroxide.—Again two liquid phases were present, and in the aqueous phase the alkali was about 1·7*N*. (3) 60% Aqueous acetone.—The solution was homogeneous and acidic throughout hydrolysis. (4) Solution of potassium hydroxide in "60%" aqueous acetone.—The solution was homogeneous and the alkali of the order of 0·03*N*. (5) 80% Aqueous acetone.—The solution was homogeneous and acidic.

The relevant kinetic data may be summarised as follows: (1, 2).—When water is the only solvent the kinetics cannot be investigated in the ordinary way because the reaction mixtures have two phases; nevertheless there can be no doubt that hydrolysis is unimolecular under these conditions since semi-quantitative observation has shown that the rate is not increased by the presence of potassium hydroxide. (3, 4, 5).—Using 80% aqueous ethyl alcohol as solvent, Ward has shown (J., 1927, 445) that the hydrolysis of α-phenylethyl chloride is unimolecular, the rate being unaffected by added potassium hydroxide; and we have supplemented Ward's work by measurement of the unimolecular rate in "60%" and "80%" aqueous acetone.

As it appeared to be impossible to realise a homogeneous bimolecular hydrolysis of α-phenylethyl chloride, we took up the study of its methyl and ethyl alcoholysis. The smaller ionising power of alcoholic than of aqueous media is expected to depress the unimolecular reaction; at the same time, the greater reactivity of methoxide and ethoxide ions than

* Holmberg did not use a solvent, whereas we carried out the reaction in acetic acid and also in benzene solution.

of hydroxide ions should facilitate bimolecular substitution. These anticipations were realised: already in methyl alcoholysis the bimolecular reaction could be made to predominate, although the unimolecular process remained important under the conditions investigated; for ethyl alcoholysis, however, we were able to examine a nearly exclusively bimolecular reaction.

The optically active chloride was alcoholysed by the following reagents: (6) Methyl alcohol.—The medium was acid throughout the change owing to the liberation of hydrogen chloride, which, however, slowly interacted with the solvent to form methyl chloride. (7) Methyl-alcoholic sodium methoxide (3·5*N*). (8) Ethyl alcohol.—The liberated hydrogen chloride reacted rather extensively with the medium. (9) Ethyl-alcoholic sodium ethoxide (2·8*N*).

The kinetic data applicable to these experiments are given in this paper. We have measured the unimolecular rates of alcoholysis in methyl and ethyl alcohol, and the total rates obtaining in the presence of sodium methoxide and ethoxide. From these results we can calculate the proportions in which the bimolecular and unimolecular substitutions occur under the conditions of the experiments with optically active material.

The optically active chloride has (10) been ammonolysed in liquid ammonia solution.

We are not able to express our results in an entirely satisfactory quantitative form because the rotatory power of optically pure α-phenylethyl chloride is not established. The highest recorded rotatory power, that obtained by McKenzie and Clough (J., 1913, **103**, 687), $[\alpha]_D^{20°}$ + 50·6°, or $\alpha_D^{20°}$ (l = 10 cm.) + 53·8°, has been equalled in some of Kenyon's investigations, and is probably not far from the maximum; for lack of any better datum we have calculated the rotations of our substitution products to correspond to chloride of this rotation. The rotary power of α-phenylethyl alcohol is known: $[\alpha]_D^{20°}$ 43·4°, or $\alpha_D^{20°}$ (l = 10 cm.) 44·0°; for hydrolysis, therefore, we are able to record the percentage optical purity of the product, and this is a lower limit to the percentage in which enantiomeric purity is retained during the substitution. By methylating α-phenylethyl alcohol through its sodium derivative we have obtained a methyl ether having $\alpha_D^{20°}$ (l = 10 cm.) 63·6°; but the rotatory power of the ether prepared by this method was not always the same, and we have no reason for believing that the highest rotation obtained represents optical purity. The same remark applies to the rotation, $\alpha_D^{20°}$ (l = 10 cm.) 74·1°, given by Kenyon and Phillips for similarly prepared α-phenylethyl ethyl ether (J., 1930, 1676; actually, the value here quoted is extrapolated from readings at other wave-lengths). In this connexion we have to remember that hydrogen in a benzyl side-chain, unlike paraffinoid hydrogen, is rather easily attacked by powerfully nucleophilic reagents such as the alkali metals, and that for these reactions, indeed for several of the reactions discussed in this paper, it is difficult to exclude the possibility of partial racemisation by mechanisms which are not directly dependent on the observed substitution. Optically pure α-phenylethylamine has $[\alpha]_D^{20°}$ 39·5° or $\alpha_D^{20°}$ (l = 10 cm.) 37·6°.

Results and Conclusions.

The results are in Table I. The left-hand columns indicate the experimental conditions, the two centre columns the proportions in which the substitution is bimolecular and unimolecular, and the right-hand columns the rotatory powers of the factors and products. In the penultimate column the rotatory powers of the products (α-phenylethyl alcohol, methyl and ethyl ether, and α-phenylethylamine) have been calculated to correspond to chloride of rotation $\alpha_D^{20°}$ (l = 10 cm.) + 53·8°. The last column records the optical purity of the products calculated from the rotatory powers given in the previous column, and the rotations, where these are known, of the optically pure materials; only an insignificant part of the recorded racemisation is due to the attack of eliminated halide ions on the undecomposed halide. It has been shown by Ward (*loc. cit.*) that the first-order rate of halogen displacement from α-phenylethyl chloride in 80% aqueous alcohol is the same whether measured by chemical analysis or polarimetrically. We have extended Ward's work to include 80% aqueous acetone or anhydrous ethyl alcohol as solvent, and although we have detected the racemising attack of halide ions, the effect is too slight to warrant the application of a correction (cf. Part I) to the figures given in the table.

TABLE I.

Expt. No.	Solvent and temp.	Concn. of KOH, HCl, etc. (*N*). Initial.	Final.	Proportion of simultaneous reactions. S_N2 (%).	S_N1 (%).	Halide, $\alpha_D^{20^\circ}$ (l = 10 cm.).	Alcohol, ether, etc. $\alpha_D^{20^\circ}$, obs.	Corr. to standard chloride.	Optical purity (%).†
		Hydrolysis of α-phenylethyl chloride.							
1a	Water (20°) *	0·00	0·13 HCl	0	100	−11·60°	+ 2·00°	− 9·3°	−17·5
1b		0·00	0·13 HCl	0	100	−47·12	+ 5·32	− 6·1	
2a		1·79	1·66 KOH	0	100	−39·20	+ 5·32	− 7·3	−16·4
2b		1·79	1·66 KOH	0	100	−47·12	+ 6·24	− 7·1	
3	60% Aqueous acetone (70°)	0·00	0·04 HCl	0	100	−34·00	+ 1·32	− 2·1	− 5·4
4		0·05	0·01 KOH	0	100	−34·00	+ 1·72	− 2·7	
5a	80% Aqueous acetone (70°)	0·00	0·19 HCl	0	100	+11·76	− 0·12	− 0·6	− 1·9
5b		0·00	0·15 HCl	0	100	−34·00	+ 0·72	− 1·1	
		Methyl alcoholysis of α-phenylethyl chloride.							
6	MeOH (70°)	0·00	0·14 HCl	0	100	+35·52	−10·24	−15·5	Low
7		3·6	3·5 NaOMe	61	39	+35·52	−32·00	−48·2	High
		Ethyl alcoholysis of α-phenylethyl chloride.							
8a	EtOH (70°) ‡	0·00	0·14 HCl	0	100	−32·60	+ 6·80	−11·2	Low
8b		0·00	0·14 HCl	0	100	−14·48	+ 2·72	−10·1	
9a		2·85	2·7 NaOEt	92·5	7·5	−32·60	+22·00	−36·2	High
9b		2·85	2·7 NaOEt	92·5	7·5	−10·52	+ 7·00	−35·7	
		Ammonolysis of α-phenylethyl chloride.							
10	NH_3 (*ca.* 20°)	0·0	3·0 NH_4Cl	0 (?)	100 (?)	+30·80	− 8·40	−14·6	−38·8
		Hydrolysis of α-phenylethyl bromide.							
11	Water (20°)	0·00	0·10 HBr	0	100	−12·80	+ 1·12	—	Low

* McKenzie and Clough (*loc. cit.*) paralleled expt. 2, but at 100°; they obtained a smaller retention of optical activity than we find at 20°.

† The negative sign signifies that configuration is inverted.

‡ Kenyon and Phillips alcoholysed the chloride by boiling it with ethyl alcohol in the presence of potassium carbonate (*loc. cit.*); their results were similar to those of expt. 8 (cf. also Bodendorf and Böhme, who describe an alcoholysis of the chloride in the presence of metallic chlorides; *Annalen*, 1935, **316**, 1).

The following conclusions may be drawn. All the substitutions, independently of mechanism, lead to a product with an inverted sign of rotation, and this, as we have proved, means in all cases an inverted configuration. Unimolecular substitutions are accompanied by much more extensive racemisation than bimolecular substitutions. In unimolecular hydrolysis racemisation becomes more and more nearly complete as the water is diluted with the inert solvent acetone. These findings are discussed in Part VI.

EXPERIMENTAL.

Optically Active α-Phenylethyl Alcohol.—For the preparation of the *dl*-alcohol we found the interaction of acetaldehyde and phenylmagnesium bromide more satisfactory than the reaction between benzaldehyde and methylmagnesium iodide. The product obtained by the former method was purer, the chief impurity being diphenyl, which, however, was eliminated when the alcohol was converted into its hydrogen phthalate. Ott's method of resolution was employed (*Ber.*, 1928, **61**, 2139), which consists essentially in crystallising the brucine salt of the hydrogen phthalate from acetone. The salt is not very soluble, and Houssa and Kenyon replaced ordinary crystallisation by repeated extraction (J., 1930, 2260). Even this process requires a large amount of acetone, and we have found it simpler merely to reflux the salt for a considerable time with a deficiency of this solvent, or to boil and cool the suspension repeatedly. Thus 400 g. of brucine salt of *l*-carbinyl ester were obtained almost optically pure by refluxing the originally precipitated salt, $[\alpha]_D$ − 31°, with about 1400 c.c. of acetone. The *l*-alcohol was isolated by known methods. The *d*-alcohol was obtained in about 60% optical purity from the brucine salt in the mother-liquors. Residues of lower activity were also obtained.

Optically Active α-Phenylethyl Chloride.—(a) *From the alcohol and thionyl chloride.* The alcohol (8 c.c.) was added to thionyl chloride (20 c.c.), and, after the reaction was complete, the excess

of thionyl chloride was pumped off at room temperature and the product distilled, b. p. 83°/21 mm. The rotation of the product (Found: C, 68·3; H, 6·4; Cl, 25·2. Calc.: C, 68·3; H, 6·4; Cl, 25·3%) varied from one experiment to another, a typical result being that alcohol with $\alpha_D^{20°}$ (l = 10 cm.) − 34·28° gave chloride with $\alpha_D^{20°}$ (l = 10 cm.) − 32·52°. When the chloride is heated with thionyl chloride racemisation occurs.

(b) *From the alcohol and hydrogen chloride.* The alcohol (10 c.c.), $\alpha_D^{20°}$ (l = 10 cm.) + 29·40°, was treated with hydrogen chloride in benzene solution until the lower aqueous layer which was formed ceased to increase. After a further hour the benzene and excess of hydrogen chloride were removed in a vacuum, and the chloride was distilled from a small amount of solid potassium carbonate. It had b. p. 78°/12 mm., $\alpha_D^{20°}$ (l = 10 cm.) − 2·80°.

Optically Active α-Phenylethyl Bromide.—(a) The alcohol (5 c.c.), $\alpha_D^{20°}$ (l = 10 cm.) + 30·80°, was slowly added to an acetic acid solution (10 c.c.) of hydrogen bromide (5 g.), and, at the conclusion of the vigorous reaction, carbon tetrachloride and water were added. The carbon tetrachloride extract was dried with potassium carbonate, and the α-phenylethyl bromide, b. p. 102°/23 mm., $\alpha_D^{20°}$ (l = 10 cm.) − 11·32°, was distilled from this reagent.

(b) The alcohol, $\alpha_D^{20°}$ (l = 10 cm.) − 37·36°, was treated with hydrogen bromide in benzene solution as described for the reaction with hydrogen chloride. The bromide had $\alpha_D^{20°}$ (l = 10 cm.) + 16·20° (Found: C, 52·0; H, 5·0; Br, 42·8. Calc.: C, 51·9; H, 4·9; Br, 43·2%).

Hydrolysis, Methyl and Ethyl Alcoholysis, and Ammonolysis of Optically Active α-Phenylethyl Halides.—The following particulars of expts. 1a—11 are supplementary to those given in Table I.

(1a) (1b) The chloride (5·3 g.) was shaken with water (300 c.c.) for 2 hours. The product, extracted with ether, was freed from the last trace of halogen by shaking with water (300 c.c.) for a further 1·5 hours. The product, when again extracted, was free from halogen (no reaction with alcoholic silver nitrate) and from styrene (no reaction with bromine in chloroform), and on distillation gave the alcohol (4 g., b. p. 102°/22 mm.) (Found: C, 78·3; H, 8·2. Calc.: C, 78·7; H, 8·2%).

(2a) (2b) The chloride (5·3 g.) was shaken with 10% aqueous potassium hydroxide (300 c.c.) for 2 hours. The product, isolated and tested for freedom from halogen and styrene as described above, was α-phenylethyl alcohol (4 g., b. p. 105°/25 mm.) (Found: C, 79·1; H, 8·3%).

(3) The chloride (5·3 g.) was hydrolysed in a mixture of acetone (600 c.c.) and water (400 c.c.) at 70° for 14 hours. The product, extracted with chloroform after large dilution with water, yielded a trace of styrene and α-phenylethyl alcohol (3 g., b. p. 98°/19 mm.) (Found: C, 77·7; H, 8·3%). The styrene was isolated and identified as its dibromide.

(4) Hydrolysis of the chloride (6·5 g.) was conducted for 22 hours at 70° in a mixture of acetone (720 c.c.), water (480 c.c.), and potassium hydroxide (3 g.). The α-phenylethyl alcohol was isolated by extraction with ether after dilution with water, and tested as usual (3 g., b. p. 98°/19 mm.) (Found: C, 77·9; H, 8·2%).

(5a) (5b) The chloride (5·3 g.) was hydrolysed in a mixture of acetone (160 c.c.) and water (40 c.c.) at 70° for 48 hours (yield of alcohol, 3 g.; b. p. 96°/17 mm., 98°/19 mm.).

(6) A solution of the chloride (6·5 g.) in methyl alcohol (300 c.c.) was kept at 70° for 18 hours. After being cooled it was diluted with 3 l. of water and extracted with ether. The product, 4 g., b. p. 66°/17·5 mm., was α-phenylethyl methyl ether, free from halogen and from styrene (Found: C, 79·2; H, 8·7. Calc.: C, 79·4; H, 8·8%).

(7) The chloride (7 g.) was alcoholysed at 70° for 18 hours with a solution of sodium methoxide prepared from sodium (50 g.) and methyl alcohol (600 c.c.). The ether (6 g.) isolated as usual contained about 15% of styrene (identified by the m. p. and mixed m. p. of its dibromide), and was therefore treated with a small excess of bromine in cold chloroform, and again isolated by distillation. It had b. p. 66°/17 mm. (Found: C, 79·3; H, 9·1%).

(8a) (8b) These experiments were conducted analogously to no. 6, the period of heating being 18 hours in one case and 45 hours in the other. The product contained a very small trace of styrene, which was removed by bromination. The α-phenylethyl ether (3·4 g.) had b. p. 82—83°/26 mm. (Found: C, 79·7; H, 9·3. Calc.: C, 80·0; H, 9·3%).

(9a) (9b) The chloride (7 g.) was alcoholysed for 18 or 45 hours at 70° with a solution of sodium ethoxide prepared from sodium (23 g.) and ethyl alcohol (350 c.c.). The styrene formed (m. p. and mixed m. p. of the dibromide) was removed by bromination. The ether (3 g.) had b. p. 74°/16 mm. (Found: C, 80·4; H, 9·6%).

(10) The chloride (10·5 g.) and liquid ammonia (15 c.c.) were kept in a closed tube at room temperature for 6 weeks. The solution was then evaporated, and the residue treated with aqueous hydrochloric acid and extracted with ether. The aqueous solution was basified and

re-extracted, and the primary base, b. p. 86°/20 mm., was distilled (Found: C, 79·3; H, 9·2; N, 11·6. Calc.: C, 79·3; H, 9·1; N, 11·6%).

(11) α-Phenylethyl bromide (4·5 g.) was shaken with water (250 c.c.) at 20° for 1 hour. The product, isolated and tested as usual, had b. p. 102°/23 mm. (Found: C, 78·3; H, 8·2. Calc.: C, 78·7; H, 8·2%).

Methylation and Ethylation of Optically Active α-Phenylethyl Alcohol.—The alcohol (6 g.) was heated under reflux with sodium (1·2 g.) in dry ether (50 c.c.) until reaction was complete (15 hours), and then methyl iodide was added, and the heating was continued for a further 2 hours. The ethereal solution was filtered, the residue was washed with ether, and the combined filtrate and washings were distilled, the α-phenylethyl methyl ether passing over at 69—71°/19 mm. Alcohol having $\alpha_D^{20°}$ (l = 10 cm.) + 29·20° and + 16·00° thus yielded ether with $\alpha_D^{20°}$ (l = 10 cm.) + 34·20° and + 23·12° respectively (Found: C, 79·0; H, 8·8. Calc.: C, 79·4; H, 8·8%). These rotatory powers are inconsistent. Similarly inconsistent results were obtained on ethylating the alcohol with ethyl iodide (cf. Kenyon and Phillips, *loc. cit.*).

Rate of Hydrolysis of α-Phenylethyl Chloride.—The analytically determined unimolecular velocity constants in 60% acetone at 67° and in 80% acetone at 70° were $1·35 \times 10^{-3}$ sec.$^{-1}$ and $9·04 \times 10^{-5}$ sec.$^{-1}$ respectively, whilst for the last-named conditions the polarimetrically determined constant rose from $9·2 \times 10^{-5}$ to $11·5 \times 15^{-5}$ sec.$^{-1}$ during the run, the mean value being $10·0 \times 10^{-5}$ sec.$^{-1}$. A typical experiment is described below, and the results are recorded in Table II.

Samples (5 c.c.) of a solution of α-phenylethyl chloride (2 g.) in acetone (80 c.c.) and water (20 c.c.) were enclosed in glass bulbs and kept at 70·0° for known times. The bulbs were subsequently broken under ethyl alcohol (150 c.c.), and their contents were titrated with 0·0447*N*-aqueous sodium hydroxide, lacmoid being used as indicator. The value of $a - x$ in the formula $k_1 = (2·303/t) \log_{10} a/(a - x)$ was got from the "infinity" titre.

TABLE II.

Time (mins.)	1	16	31	46	61	76	106
Titre (c.c.)	0·03	1·29	2·63	3·85	5·10	6·10	8·06
$k_1 \times 10^5$ (sec.$^{-1}$)	—	—	8·56	8·69	9·01	8·95	9·15
Time (mins.)	136	181	241	306	391	4320	8640
Titre (c.c.)	9·65	11·80	13·78	15·30	16·75	18·37	18·40
$k_1 \times 10^5$ (sec.$^{-1}$)	9·18	9·50	9·59	9·73	—	—	—

Rate of Methyl Alcoholysis of α-Phenylethyl Chloride.—The method for the estimation of the unimolecular constant k_1 at 70·0° was just the same as for hydrolysis except that the solvent was methyl alcohol. One of the bulbs was used in order to obtain the value of a: it was broken under alcohol, and the material treated with excess of silver nitrate, which was back titrated with ammonium thiocyanate. Owing to the slow interaction between the liberated hydrogen chloride and the solvent methyl alcohol, the constants fall towards the end of a run, as is illustrated by the experiment in Table III; hence the special measures adopted to secure an "infinity titre" undisturbed by this effect.

In order to obtain a predominantly bimolecular reaction it was necessary to use large concentrations of sodium methoxide. The method of sealed bulbs was again employed. They were broken under ether, and the solutions extracted twice with water. The aqueous solution was acidified with nitric acid, treated with excess of standard silver nitrate, and back-titrated with ammonium thiocyanate, ferric alum being used as indicator. The total reaction was thus measured, and the part due to the unimolecular process was calculated from the known value of k_1 and subtracted; the residual reaction was then used for the calculation of the bimolecular constant k_2.

At 70·0° we find $k_1 = 4·35 \times 10^{-4}$ sec.$^{-1}$, and for concentrations of sodium methoxide in the neighbourhood of 3*N* (but low concentrations of chloride), $k_2 = 2·46 \times 10^{-4}$ sec.$^{-1}$ g.-mol.$^{-1}$ l.

TABLE III.

Time (mins.)	10	11	15	20	25	35	45	55	80	∞ *
Titre (c.c.)	5·14	5·65	7·00	8·25	9·18	10·80	12·35	13·05	14·60	18·80
$k_1 \times 10^4$ (sec.$^{-1}$)	4·41	4·63	4·56	4·37	4·10	3·81	3·76	3·43	3·02	—

* From the decomposition with silver nitrate.

Rate of Ethyl Alcoholysis of α-Phenylethyl Chloride.—The unimolecular constant k_1 was estimated as described for methyl alcoholysis, but owing to the smaller rate of ethyl alcoholysis

there is more opportunity for the subsequent reaction between hydrogen chloride and the solvent alcohol. Consequently the constants calculated in the course of a run fall markedly, and, indeed, the titres cease rising after a time and even begin to fall again. An experiment is reported in Table IV. The reaction between hydrogen chloride and the solvent alcohol was demonstrated by following this reaction at the same temperature, 70°:

Time (hours)	0·00	7·50	15·25	24·00	39·50	90·00
Titre (c.c. of 0·0447N-alkali)	13·70	11·40	9·60	8·00	5·95	2·90

The bimolecular constant k_2 was measured as described for methyl alcoholysis except that, as the whole reaction is predominantly bimolecular in the presence of moderate concentrations of sodium ethoxide, the concentrations used were of the order of N.

At 70·0° we find $k_1 = 3·75 \times 10^{-5}$ sec.$^{-1}$, and $k_2 = 1·67 \times 10^{-4}$ sec^{-1}. g.-mol.$^{-1}$ l. Determined by the polarimetric method, k_1 rose from $4·0 \times 10^{-5}$ to $5·4 \times 10^{-5}$ sec.$^{-1}$ during the run, the mean value being $4·62 \times 10^{-5}$ sec.$^{-1}$.

TABLE IV.

Time (mins.)	60	120	180	240	300	450	810	1020	1440
Titre (c.c.)	1·75	4·10	5·85	7·20	8·30	10·20	11·65	11·60	10·50
$k_1 \times 10^5$ (sec.$^{-1}$)	2·99	3·81	3·83	3·81	3·70	3·37	2·36	1·86	—

The "infinity" titre in the absence of the reaction between hydrogen chloride and the solvent is 17·06 c.c., this figure being obtained as described for methyl alcoholysis.

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254. *Reaction Kinetics and the Walden Inversion. Part III. Homogeneous Hydrolysis and Alcoholysis of α-Bromopropionic Acid, its Ester and Anion.*

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The kinetics-controlled stereochemical examination of the substitution of Hal by OR is here continued for a group of cases, in which, besides hydrogen and alkyl groups, a carboxyl group in one of its various modifications is attached to the seat of substitution. The reactions studied were the methoxylation or hydroxylation or both of methyl α-bromopropionate, non-ionised α-bromopropionic acid and the α-bromopropionate ion.

The determination of the relationship between configuration and sign of rotation, and the fixing of maximal rotatory powers, presented no difficulty. Each of the reactions to be examined for the optical effect was examined kinetically. A study was made of salt effects, which are shown, both experimentally and theoretically, to be opposite for bi- and uni-molecular substitutions, and to afford, therefore, an auxiliary criterion of mechanism, especially valuable when rates and reaction orders are not decisive. The methoxylation of methyl α-bromopropionate is a second-order reaction in alkaline solution, and first-order in acidic solution. In the alkaline hydroxylation and methoxylation of the anion, second- and first-order reactions take place side by side. The hydroxylation of the non-ionised bromo-acid is a first-order process. We here use, as is customary, the terms "second" and "first order" to indicate the type of kinetic equation which a reaction follows; the terms "bimolecular" and "unimolecular" relate to mechanism, as has already been illustrated (this vol., pp. 1177, 1187); we have also seen that there is not always a simple and exclusive correspondence between order and mechanism. In the present series of examples the kinetically second-order reactions are all mechanistically bimolecular, and so also are the first-order reactions of the ester and undissociated acid; but the first-order reactions of the anion are unimolecular.

The optical investigation was complicated by racemising processes independent of the substitution, and these had to be sorted out. This done, it was found that the

five bimolecular reactions invert configuration whilst the two unimolecular reactions retain it, and that in no case is there any detectable racemisation definitely attributable to substitution by any one mechanism; although, of course, the concurrence of two mechanisms which produce two opposite stereochemical effects will cause racemisation. Quantitative particulars are given, together with a conspectus of the results of Parts I—III.

In this communication we report on steric orientation, under conditions defined with respect to reaction kinetics, in hydrolytic and alcoholytic replacements of the halogen atom in α-bromopropionic acid, its anion, and methyl ester.

By definition, *d*-lactic acid is that lactic acid which gives dextrorotatory salts, $(+)CH_3\cdot CH(OH)\cdot CO_2^-$. The acid itself is lævorotatory, $(-)CH_3\cdot CH(OH)\cdot CO_2H$, but gives dextrorotatory methyl and ethyl esters $(+)CH_3\cdot CH(OH)\cdot CO_2R$, dextrorotatory methyl and ethyl ethers, $(+)CH_3\cdot CH(OR)\cdot CO_2H$, and dextrorotatory esters of these ethers, $(+)CH_3\cdot CH(OR)\cdot CO_2R$. Its ethyl ester gives a dextrorotatory acetyl derivative, $(+)CH_3\cdot CH(OAc)\cdot CO_2Et$, a lævorotatory benzoyl derivative, $(-)CH_3\cdot CH(OBz)\cdot CO_2Et$, and a dextrorotatory *p*-toluenesulphonyl derivative, $(+)CH_3\cdot CH(OSO_2\cdot C_7H_7)\cdot CO_2Et$. All these compounds can be prepared from lactic acid without exchanging a bond attached to the asymmetric carbon atom, and hence all must be configuratively related: they are "*d*"-derivatives. Kenyon, Phillips, and Turley have shown (J., 1925, **127**, 399) that the (+)*p*-toluenesulphonyl derivative on treatment with potassium benzoate yields the (+)benzoyl compound. This reaction involves an inversion, since its product belongs to the *l*-series, and it may therefore be assumed that the corresponding reaction with lithium chloride would also give a product belonging to the *l*-series:*

$$d(+)\text{-}CH_3\cdot CH(OSO_2\cdot C_7H_7)\cdot CO_2Et \begin{cases} \xrightarrow{OBz^-} l(+)\text{-}CH_3\cdot CH(OBz)\cdot CO_2Et \\ \xrightarrow{Cl^-} l(-)\text{-}CH_3\cdot CHCl\cdot CO_2Et \end{cases}$$

The chloro-ester thus obtained was lævorotatory, and hence a dextrorotatory ethyl α-chloropropionate is configuratively related to *d*-lactic acid. Similar experiments with sodium bromide and potassium iodide as reagents showed that dextrorotatory ethyl α-bromopropionate and ethyl α-iodopropionate have the same kind of configuration as *d*-lactic acid. Dextrorotatory α-chloropropionic acid and dextrorotatory methyl and ethyl α-chloropropionates can be shown by hydrolysis, esterification, or preparation through a common acid chloride to be configuratively related. Dextrorotatory α-bromopropionic acid can be similarly connected with its dextrorotatory methyl and ethyl esters (part of the evidence is in this paper). Hence all these halogenopropionic acids and their esters, when dextrorotatory, are configuratively related to *d*-lactic acid. These are the conclusions on which we base the interpretation of our observations of rotatory power. Identical conclusions have been reached in other ways by Freudenberg, Markert, and Lux (*Ber.*, 1927, **60**, 2447; 1928, **61**, 1083), Kuhn and Wagner-Jauregg (*Ber.*, 1928, **61**, 481, 504), and Bancroft and Davis (*J. Physical Chem.*, 1931, **35**, 1624), and directly opposing conclusions by Levene and Haller (*J. Biol. Chem.*, 1929, **81**, 703; **83**, 185) and Clough (J., 1918, **113**, 551; 1926, 1674).

One of our main objects was to compare the steric orienting influence of an esterified and unesterified carboxyl group, since special effects were expected to arise from the development of an anionic charge on the latter. It was found impossible to displace the halogen atom in methyl α-chloro- or α-bromo-propionate by treatment with potassium hydroxide in aqueous acetone without first completely hydrolysing the carbomethoxyl group; and even α-chloropropionamide on treatment with aqueous alkali underwent almost complete hydrolysis with respect to the carboxylamide group before displacement of the

* This type of argument distinguishes a number of Kenyon's later papers on other optically active compounds; it was not used explicitly in relation to the comparatively early work cited. It is employed or accepted by us always with the reservation that there must be definite reason for presuming that the reactions taken as analogous are actually of the same kinetic type. A case in which this requirement was not fulfilled was mentioned in Part II.

halogen could be observed. We therefore commenced this investigation with methoxylation instead of hydroxylation as the substitution process, since the former could be studied both for methyl α-bromopropionate and for the α-bromopropionate ion without altering the form of the carboxyl group in either compound. Later we devised an investigation of hydroxylation which confirms and supplements the study of methoxylation.

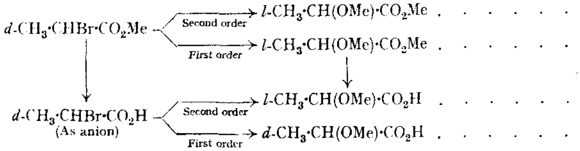
(A) *Methoxylation.*

It will be convenient to give a qualitative summary of the observed relations, and then, for each of the reactions mentioned, to add the necessary quantitative particulars.

The methoxylation of methyl and of sodium α-bromopropionate has been effected by means of sodium methoxide in absolute methyl-alcoholic solution. The following transformations have been realised:

SCHEME A.

Methyl Alcoholysis of Methyl and Sodium α-Bromopropionate.



(I) (II) (III) (IV)

In this scheme the symbols *d* and *l* represent, not only the rotations, but also the configurations. It will be seen that three of the methoxylation reactions lead to inversion and one to retention of configuration.

Reaction I (Ester + Sodium Methoxide).—We may now consider the methoxylation of the methyl ester in further detail. The reaction in the absence of sodium methoxide is extremely slow. In the presence of sodium methoxide (0·2—0·5*M*) the methoxylation is rather rapid and fairly accurately of the second order (reaction I), although the constants seem to be slightly higher in the more concentrated methoxide solutions. The specific rate at 25·0° may be taken as 0·00042 sec.$^{-1}$ g.-mol.$^{-1}$ l. over the range of concentrations used for the optical investigation. This means that if the original solution were 0·5*M* with respect to each reagent the period of half-change would be 80 minutes.

The optical effect is typically represented by the following record. A solution 0·478*M* with respect to both sodium methoxide and methyl α-bromopropionate having $\alpha_D^{20°}$ (l = 10 cm.*) −53·2° was kept at 25° for 19 hours, by which time 93% of the material must have undergone reaction; the methoxy-ester, which was then isolated and purified, had $\alpha_D^{20°}$ +1·94°. This figure requires correction for the incompleteness of conversion. We shall show later that during the methoxylation the bromo-ester independently undergoes racemisation, and does so at such a rate that the 7 mols. % remaining after 19 hours would be quite inactive. If this material also had been methoxylated the isolated product would have been diluted with a corresponding amount of inactive methoxy-ester, and the rotation would have been only 93% of what was found. We cannot describe this reduced value as the rotation which the methoxy-ester would have if isolated after infinite time, because the methoxy-ester itself undergoes a slow racemisation. Therefore we shall take as the corrected result that rotation which would be observed if the conversion proceeded naturally during the period of the experiment, and was then completed suddenly. The rotations are then as follows:

$$(\alpha_D^{20°} -53{\cdot}2°)\ CH_3{\cdot}CHBr{\cdot}CO_2Me \longrightarrow CH_3{\cdot}CH(OMe){\cdot}CO_2Me\ (\alpha_D^{20°} +1{\cdot}80°) \quad . \ . \ . \quad (I)$$

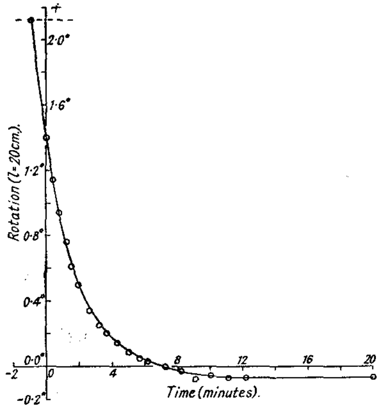
These figures indicate that much racemisation has occurred, and we can ascertain how much. A lower limit to the rotation of optically pure methyl α-bromopropionate is set by the fact that we have prepared a specimen having $\alpha_D^{20°}$ +68·6°. A more accurate figure follows if we adopt Ramberg's carefully established value $\alpha_D^{20°}$ 49° for the rotatory

* All rotations relate to l = 10 cm. throughout, unless otherwise specified.

power of α-bromopropionic acid (*Annalen*, 1909, **370**, 234); because we have hydrolysed the ester to the acid under conditions which preclude appreciable racemisation. The best value for the rotatory power of methyl α-bromopropionate is thus $\alpha_D^{20^\circ}$ 74°. The rotation of optically pure methyl α-methoxypropionate is $\alpha_D^{20^\circ}$ 95° (Purdie and Walker, J., 1899, **75**, 485; Irvine, J., 1906, **89**, 935). It follows that in the experiment recorded above, a bromo-ester having 72% of its maximal rotation has given a methoxy-ester with only 1·90% of its maximal rotation, and that therefore the optically pure bromo-ester would have given a methoxy-ester with 2·65% of its proper rotatory power.

Now this racemisation might occur in three ways, *viz.*, before, during, or after the substitution. All the compounds with which we are concerned in this paper contain a potentially ionising hydrogen atom (α- to carboxyl), and hence are capable of undergoing a racemisation, catalysed by methoxide ions, which is nothing to do with replacement in

Fig. 1.



Fall of rotation of a solution of methyl *d*-α-bromopropionate (0·5*M*) and sodium methoxide (0·5*M*) in methyl alcohol at 25°.

which the methoxide ions engage. In so far as the loss of optical activity under consideration does not accompany substitution, we expect it to take place mainly before this reaction, because Wilson has shown (J., 1934, 98) that the rates of racemisations which involve hydrogen-ionisation are regularly related to the electron-affinity of the groups joined to the asymmetric atoms; and, as bromine has a higher electron-affinity than methoxyl, the bromo-ester should be more rapidly racemised than the methoxy-ester. We must determine how much racemisation can be accounted for as having occurred before and after substitution, in order to isolate that part which essentially depends on the substitution.

Fig. 1 shows the variation with time at 25° of the rotation of a solution initially 0·508*M* with respect to both methyl α-bromopropionate and sodium methoxide. From this curve it is qualitatively obvious that most of the racemisation observed in the substitution must have taken place in the bromo-ester before substitution occurred: the rotatory power falls to zero in 7·9 minutes when only 9·0% of material has undergone methoxylation; and after a further equal period it becomes practically constant although only 16·7% of substitution has occurred. The methoxy-ester which was isolated was formed in a reaction which occupied many hours, but its optical activity must have arisen entirely from the small

amount that was formed in the first few minutes, when the bromo-ester still retained an appreciable activity.

Considering more quantitatively the experiment in which the change of rotation with time was followed, we note that rotation at any instant is the sum of two partial rotations, one due to the bromo-ester and the other to the methoxy-ester. The partial rotation of the bromo-ester can be considered to be the product of its instantaneous concentration and instantaneous rotatory power. We define rotatory power for this purpose as the rotation which would be observed in the same polarimeter tube if material of the same quality in unit concentration alone contributed to the rotation. The partial rotation of the methoxy-ester is a similar product of a concentration and a rotatory power. All four quantities, the two concentrations and the two rotatory powers, vary with time. In the case of rotatory powers, moreover, two kinds of instantaneous value must in general be distinguished, *viz.*, that belonging to the whole of the compound present at the instant under consideration, and that applying to a small increment of material produced at that instant. For the bromo-ester, which is being destroyed all the time, the two sorts of rotatory power, that of the whole and that of the (negative) increment, are the same; but for the methoxy-ester, which is being produced continuously from bromo-ester of varying rotatory power, they are in general different.

The time-variation of the concentration of bromo-ester is known, because we have studied the reaction kinetically. The time-variation of the rotatory power of the bromo-ester depends on an unknown rate-constant for the catalysed racemisation of this substance, and on the concentration of the catalysing methoxide ions. This concentration is time-variable, but the law of the variation is known from our kinetic results. Hence the whole function giving the time-variation of the partial rotation due to bromo-ester can be expressed with the inclusion of one unknown rate constant.

The time-variation of the partial rotation of the methoxy-ester is due to two causes: first, the ester is being produced from bromo-ester of continually changing rotatory power; secondly, no sooner is the methoxy-ester formed than it begins to racemise. We have seen how to calculate the rotatory power of the bromo-ester present at any moment. The rotatory power of a small increment of methoxy-ester produced from the bromo-ester at that moment will bear a constant ratio to the rotatory power of the bromo-ester from which it is derived; it is indeed this ratio which we are chiefly interested to determine. The rotatory power of a newly formed increment of methoxy-ester will therefore be expressed by a function involving two unknown constants, the unknown rate-constant previously mentioned for racemisation of the bromo-ester and the required ratio of rotatory powers characterising the substitution. At a later time the rotatory power of this same small increment of methoxy-ester will have diminished on account of its racemisation, and we can calculate by how much, because, as mentioned later, we have determined the rate constant for the catalysed racemisation of the methoxy-ester by direct experiment, and we know the law of variation with time of the concentration of the catalysing methoxide ions. The whole amount of methoxy-ester present at any time contains the increments formed at all previous times, and hence a suitable integration will give the partial rotation of the methoxy-ester in terms of the two unknown constants.

Adding together the expressions for the two partial rotations we obtain an equation for the curve of Fig. 1; and by comparison with the experimental results we can evaluate the unknown constants.

As stated above, we directly determined the rate of racemisation of methyl α-methoxy-propionate as catalysed by methoxide ions: the specific rate in methyl alcohol at 25° was 0·00000803 sec.$^{-1}$ g.-mol.$^{-1}$ l. The time of half-change in a solution 0·5*M* with respect to sodium methoxide would be 47·9 hours. Since in the methoxylation experiment half the original methoxide ions disappear in the first 80 minutes, it is qualitatively evident that racemisation of the methoxy-ester does not account for more than a small proportion of the total observed loss of optical activity.

As the detailed calculation corresponding to the foregoing analysis of the curve in Fig. 1 is rather complicated, we relegate it to an appendix. By fitting the theoretical equation to the curve we find the value 0·0148 sec.$^{-1}$ g.-mol.$^{-1}$ l. for the specific rate of racemisation

of the bromo-ester by methoxide ions in methyl alcohol at 25°. If no methoxylation occurred, the time of half-change for the racemisation of the bromo-ester in a solution 0·5*M* with respect to sodium methoxide would be 1·55 minutes, a figure which may be compared with the 80 minutes half-change period for methoxylation.

The other unknown quantity, *viz.*, the ratio of rotatory powers characteristic of the substitution, is found to be substantially equal to the ratio of rotatory powers of the optically pure compounds, but with a negative sign on account of the inversion. We can calculate how much racemisation occurred in the bromo-ester and in the methoxy-ester under the conditions of the experiment in which after conversion the latter was isolated. If the original bromo-ester had been optically pure, then its racemisation prior to substitution would have led in a completed substitution to a methoxy-ester with 2·7% of its maximal optical activity. The racemisation of the methoxy-ester after its formation by substitution up to the moment at which the experiment was stopped must reduce the optical activity further to 2·6% of the maximum. Any racemisation *accompanying* substitution would reduce it further still. The observed optical activity, calculated to correspond to optically pure starting material, was 2·65% of the maximum. This activity leaves no margin for the occurrence of any appreciable racemisation in the act of substitution, which must therefore have taken place with a substantially complete inversion of configuration.

In order to estimate the degree of consistency obtainable by means of this derivation we carried out a second experiment with dextrorotatory bromo-ester and different initial concentrations. A solution 0·245*M* with respect to both sodium methoxide and the bromo-ester was kept at 25° for 70·0 hours, and the methoxy-ester was isolated and purified; it had $\alpha_D^{20^\circ}$ −1·06°. The bromo-ester, which originally had $\alpha_D^{20^\circ}$ +32·2°, must have been methoxylated to the extent of 96%. Correcting the rotation of methoxy-ester for incompleteness of conversion under the conventions used for the previous experiment, we find :

$$(\alpha_D^{20^\circ} +32{\cdot}2^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2Me \longrightarrow CH_3{\cdot}CH(OMe){\cdot}CO_2Me\ (\alpha_D^{20^\circ} -1{\cdot}02^\circ) \quad . \quad . \quad . \quad (I)$$

In this experiment a bromo-ester the rotation of which is 43% of its maximum gives a methoxy-ester with a rotation which is only 1·07% of its maximum; therefore under these conditions the optically pure bromo-ester would give a methoxy-ester with a rotation equal to 2·5% of its maximal value. Calculation shows that in this case the racemisation of an initially optically pure bromo-ester prior to substitution would lead to the formation of a methoxy-ester with 2·8% of its maximal rotation; and that racemisation of the methoxy-ester after its formation by substitution would reduce this value to 2·6%. In this case also, therefore, the experimental result leaves no margin for appreciable racemisation in the act of substitution.

Reaction II (*Ester* + *Methyl Alcohol*).—The first-order methoxylation of methyl α-bromopropionate (reaction II) is so slow in comparison with the second-order process that we could not observe the former in the presence of appreciable amounts of sodium methoxide; nor could it be studied at so low a temperature as 25°. It was therefore investigated in the absence of sodium methoxide and at 100°; the solution of the bromo-ester, although originally neutral, is acid with liberated hydrobromic acid throughout the course of the change. We have proved experimentally that under these conditions the reaction is kinetically of the first order, the rate constant being 0·00000295 sec.$^{-1}$: the period of half-change is 67 hours. However, although the rate law is obeyed fairly accurately over most of the reaction, disturbances affect the later stages in prolonged experiments. This is due to the action of the liberated hydrogen bromide on the solvent methyl alcohol, which it converts into methyl bromide and methyl ether, the water set free in this process causing hydrolysis of the methyl α-methoxypropionate and any remaining methyl α-bromopropionate with the production of free carboxylic acids. The etherification is catalytic in the sense that, given sufficient time, more methyl alcohol can be converted into ether than corresponds stoicheiometrically to the quantity of hydrogen bromide responsible for the change : the hydrogen bromide originally consumed in the formation of methyl bromide must be regenerated in the stage in which the ether is produced, the whole cycle resembling that which obtains in etherification with sulphuric acid as catalyst.

Experiments with optically active material were carried out in the first place by heating the bromo-ester at 100° for shorter times than those at which the disturbance mentioned becomes appreciable. The substitution was then only partial, and the methyl α-methoxypropionate and residual methyl α-bromopropionate were only partly separated. It was found that the methyl α-methoxypropionate produced from *d*-methyl α-bromopropionate was lævorotatory, even although the specimen examined still contained residual dextrorotatory bromo-ester. This showed qualitatively that substitution is accompanied by an inversion of configuration. In order to obtain quantitative results, we allowed the substitution to proceed nearly to completion, although, as explained above, hydrolysis of the carbomethoxyl group takes place under these conditions. However, preliminary experiments having shown that the bromo-ester is at least largely methoxylated before it is appreciably hydrolysed, we were able to carry the conversion of the bromo-ester through to the methoxy-acid, and to treat the optical results as relating essentially to a substitution of the bromo-ester.

Methyl α-bromopropionate having $\alpha_D^{20^\circ}$ +29·6° was methoxylated by heating a 0·60*N*-solution in methyl alcohol at 100° for 230 hours. From the known rate of substitution it can be calculated that methoxylation should have taken place to the extent of 91%. During the subsequent isolation of the methoxy-acid a part of the remaining 9 mols.% of bromo-acid was eliminated: analysis showed the presence of 7·0% by weight or 4·5 mols.% of this substance. The rotation of the specimen, which therefore contained 95·5 mols.% of methoxy-acid, was $\alpha_D^{20^\circ}$ −2·72°. The experiments and calculations described below will show that bromo-ester present in this specimen would not contribute appreciably to the observed rotation, and hence we can calculate the rotation which the methoxy-acid would have exhibited if the bromo-acid, an optically inactive diluent, had been completely removed. The proportion by volume of the diluent is 4·5%, and hence the corrected rotation of the methoxy-acid is −2·85°. However, the value in which we are really interested is, not the rotation of the methoxy-acid formed after 230 hours, but the rotation with which the acid would be found after completion of the substitution. Completion would replace the 9 mols.% of inactive bromo-compound by 9 mols.% of inactive methoxy-acid, and hence the rotation of the total methoxy-acid formed in a complete substitution would be only 91% of −2·85°. Our corrected result is therefore as follows:

$$(\alpha_D^{20^\circ} +29{\cdot}6^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2Me \longrightarrow CH_3{\cdot}CH(OMe){\cdot}CO_2H\ (\alpha_D^{20^\circ} -2{\cdot}60^\circ) \quad . \quad . \quad . \quad (II)$$

Evidently much racemisation has occurred. The rotation of optically pure methyl α-bromopropionate is $\alpha_D^{20^\circ}$ 74° (p. 1211). Purdie and Irvine determined the rotation of optically pure methyl α-methoxypropionate, and we have hydrolysed the methyl ester to the acid under conditions which preclude perceptible racemisation. Combining the results, we find the maximal rotation of the acid to be $\alpha_D^{20^\circ}$ 93·5°. From these data it can be calculated that under the conditions of the above experiment an optically pure bromo-ester would have given a methoxy-acid with 7·0% of its full rotation.

We have now to decide how much of the loss of optical activity represented by this figure occurs before, during, and after the substitution. Actually none occurs after substitution, the methoxy-ester and acid being optically stable under the experimental conditions. In order to find out how much takes place before substitution, it is necessary to know the rate of racemisation of the bromo-ester, and to this end we have studied the variation with time of the rotation of a methyl-alcoholic solution of the bromo-ester placed under the same experimental conditions. A solution, 0·60*N* with respect to the bromo-ester, was kept at 100°; and from time to time samples were withdrawn for the measurement of their rotation at the room temperature. The results are shown in Fig. 2.

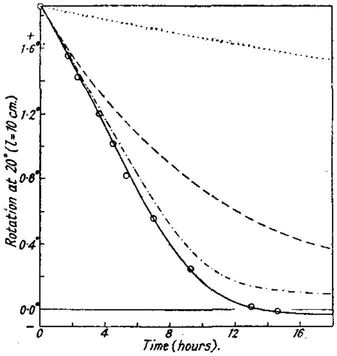
It is qualitatively evident that most of the racemisation observed in the methoxy-compound which was isolated after 230 hours must have taken place prior to the substitution. The rotation–time curve falls to zero rotation in 14 hours, when, as we can calculate from the known rate of substitution, only 14% of the bromo-ester has been methoxylated. At this point the lævorotation of the methoxy-ester formed compensates the dextrorotation still remaining in the bromo-ester; but the former contribution must be

small, as the " isolation " experiment shows, and hence the latter must be small also. It is not difficult to see that more than 90% of the optical activity of the bromo-ester must have been destroyed in 14 hours, even although 86% of the ester still remained unsubstituted.

We may next qualitatively consider the shape of the rotation curve, which is unusual: the curve runs nearly straight for much of its course, as though it represented a reaction of zero order; and then it turns rather sharply into the direction of the time axis.

We may simplify qualitative discussion by disregarding the small contribution of the methoxy-ester to the rotation, and considering the experimental curve as though it represented only the destruction of optically active bromo-ester by racemisation and substitution. We shall show eventually that the curve for partial rotation due to the bromo-ester runs as indicated by the chain-line in Fig. 2; but it is obvious at present that

FIG. 2.



The full-line curve represents the loss of optical activity from a 0·60*N*-methyl-alcoholic solution of methyl α-bromopropionate at 100°. Four effects contribute to produce this curve. The dotted curve shows the fall in the partial rotation of bromo-ester which would be caused by methoxylation only. Taking account of the hydrogen-racemisation in addition, we obtain the broken-line curve. Now, counting in the bromine-racemisation, we derive the chain-line curve, which represents the actual partial rotation due to bromo-ester. Allowance being made finally for the partial rotation of the methoxy-ester, we obtain a curve indistinguishable from the experimental curve.

this curve will be quite close to the experimental curve, being, in fact, merely lifted slightly at the right-hand end in order to be asymptotic to the time-axis instead of to a line just below it.

Part of the fall of rotation due to bromo-ester arises from the disappearance of this substance in the first-order substitution. We know already that the rate constant for this reaction is 0·00000295 sec.$^{-1}$ (half-change 67 hours), and we can draw a curve (the dotted line in Fig. 2) to represent how the fall of rotation would run if this effect acted alone. Fixing attention for the moment on the *initial* rate of fall of rotation, we see that methoxylation accounts for only slightly more than 10% of the observed initial fall.

The remainder of the initial rate of decrease of the partial rotation of the bromo-ester is due to a first-order racemisation of the bromo-ester itself. This is the reaction which depends on the presence of an α-hydrogen atom (prototropy), and we may call it the " hydrogen-racemisation " in order to distinguish it from another racemising process mentioned later. Hydrogen-racemisation acting alone would lead to an exponential fall of rotation, and we can roughly evaluate the rate constant: continuing to neglect the partial rotation of the methoxy-ester, we may take the whole of the difference between the initial

slopes of the experimental curve and of the curve calculated for the fall of partial rotation of bromo-ester due to methoxylation as representing the initial rate of hydrogen-racemisation. The rate constant thus obtained is 0·000025 sec.$^{-1}$ (half-change 7·7 hours). This value must be a little too high, but it is obvious that the rate of hydrogen-racemisation alone is about ten times greater than the rate of substitution.

In the alkaline methoxylation of the bromo-ester (Fig. 1) hydrogen-racemisation was very rapid. In the acid reaction now under consideration it is relatively very slow. Its slowness furnishes the opportunity for the incursion of another racemisation process, which is intrinsically rather slow, and was therefore not observed in the presence of the rapid, alkali-catalysed hydrogen-racemisation. This is the racemising attack of bromide ions on the bromo-ester, the bromide ions being, of course, those liberated in the methoxylation. This mode of racemisation depends, not on the presence of α-hydrogen, but on that of α-bromine: the bromide ion displaces the bromine atom with inversion in the well-known way. We can call this process the " bromine-racemisation." Its rate varies with time in a rather complicated way because the supply of one of the reactants (bromide ion) is dependent on a distinct reaction. However, one can see qualitatively what shape the reaction–time curve will have: initially the rate is zero because there are no bromide ions; and finally it is zero because there is no optically active bromo-ester. The rate must therefore pass through a maximum, and the reaction–time curve must be sigmoid with a horizontal asymptote at each extremity.

FIG. 3.

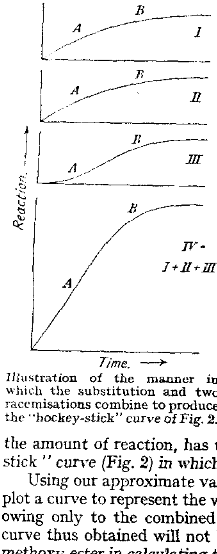


Illustration of the manner in which the substitution and two racemisations combine to produce the "hockey-stick" curve of Fig. 2.

These considerations provide the qualitative explanation of the initial linearity of the observed rotation–time curve and of its rather sharp turn near the time axis. There are three contributory effects—apart from the neglected partial rotation of the methoxy-ester. The first is the methoxylation, the reaction–time curve for which must be everywhere concave to the time axis (Fig. 3, I). The second is the hydrogen-racemisation for which the same statement is true (Fig. 3, II). The third is the bromine-racemisation, the reaction–time curve for which is sigmoid (Fig. 3, III). When these curves are compounded, then in the region marked A the curvature of III opposes the curvatures of I and II, so that the resultant curve is almost straight; whilst in region B the curvature of III reinforces the curvatures of I and II, and the resultant curve exhibits a rather sharp turn in the direction of the time axis (Fig. 3, IV). This curve, in which the ordinates are supposed to represent the amount of reaction, has to be turned upside down for comparison with the " hockey-stick " curve (Fig. 2) in which the ordinates are optical rotations.

Using our approximate value for the rate constant of the hydrogen-racemisation we can plot a curve to represent the way in which the partial rotation of the bromo-ester would fall owing only to the combined action of methoxylation and hydrogen-racemisation. The curve thus obtained will not be accurate because we neglected the partial rotation of the methoxy-ester in calculating the rate constant; nevertheless it must lie only slightly below the accurate curve, which, calculated as described below, is shown by a broken line in Fig. 2. The divergence of our approximate curve from the experimental curve gives an approximate measure of the rate of the bromine-racemisation. Initially, the difference of the ordinates of the two curves increases with the square of the time, *i.e.*, the difference of slope increases linearly with the time. The difference of slope represents the excess rate of loss of optical activity due to the bromine-racemisation. By comparing the time-rate of increase of this excess rate with the known time-rate of increase in the concentration of the attacking bromide ions we can estimate the rate constant. The value obtained is 0·00075 sec.$^{-1}$ g.-mol.$^{-1}$ l.

Having now obtained approximate values of the rate constants of the two racemisation processes, we can calculate approximately the proportion in which optical activity should be retained in the methoxy-ester formed at " infinite " time if no loss of activity occurred during the substitution itself. When we compare the value thus obtained with the percentage retention of activity derived from experiment, we find that the substitution must have been accompanied by a substantially complete inversion.

This approximate result now enables us to refine the whole of the previous calculations by taking into account the fourth factor which contributes to the observed rotation, *viz.*, the hitherto neglected partial rotation of the methoxy-ester. Assuming that each small increment of methoxy-ester has the same proportion of its maximal rotatory power (with inverted sign) as has the bromo-ester from which it was formed, we can calculate for any time the partial rotation of the methoxy-ester which has accumulated up to that time. Subtracting this partial rotation from the observed rotation, we obtain the corrected curve, represented by a chain-line in Fig. 2, for the partial rotation due to bromo-ester. By measuring the initial slope of this curve we obtain a more accurate value for the rate constant of the hydrogen-racemisation, *viz.*, 0·0000225 $sec.^{-1}$. From this value we can calculate a more accurate curve, the broken line in Fig. 2, for the fall in the partial rotation of the bromo-ester due to methoxylation and hydrogen-racemisation. From the divergence between this curve and that for the corrected partial rotation of bromo-ester, we can find a better value, 0·00076 $sec.^{-1}$ $g.\text{-}mol.^{-1}$ l., for the rate constant of the bromine-racemisation. Then, using these improved values, we can again calculate the proportion in which optical activity should be retained in a complete methoxylation if the only cause for loss of activity were racemisation prior to substitution. The answer is 7·3%. The observed value was 7·0%. These figures leave no room for any considerable racemisation as an *accompaniment* of the act of substitution, which therefore proceeds with substantially complete inversion.

The above reasoning can be checked by setting up a theoretical equation for the rotation–time curve, as we have done in the Appendix. Into this equation we can insert the values already derived for the rate constants of the methoxylation and two racemisations, and the ratio of rotatory powers characterising the methoxylation. The equation should now represent the observations throughout their whole range; and the test thus indicated is real, because we used only initial rates in order to calculate our rate constants. Actually the " theoretical " curve lies so closely on that obtained experimentally that they cannot be shown separately in Fig. 2.

Reactions III and IV (Sodium Salt + Sodium Methoxide).—Continuing the detailed description of the reactions formulated in Scheme A, the connexion of the rotatory powers of the bromo- and the methoxy-ester with those of the bromo- and the methoxy-acid obtainable from them by saponification is as shown by the following observed rotations :

$$(\alpha_D^{21^\circ} +28{\cdot}9^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2Me \longrightarrow CH_3{\cdot}CHBr{\cdot}CO_2H\ (\alpha_D^{18{\cdot}5^\circ} +19{\cdot}1^\circ)$$

$$(\alpha_D^{20^\circ} -53{\cdot}7^\circ)\ CH_3{\cdot}CH(OMe){\cdot}CO_2Me \longrightarrow CH_3{\cdot}CH(OMe){\cdot}CO_2H\ (\alpha_D^{20^\circ} -52{\cdot}8^\circ)$$

In each case the saponification is so rapid that the rotations of the acids can be only slightly if at all affected by racemisation.

The methoxylation of sodium α-bromopropionate (reactions III and IV) proceeds at a speed convenient for measurement at 64°, and we have made this the standard temperature for both the kinetic and the optical observations on the sodium salt. As Senter and Wood have already concluded (J., 1916, **109**, 681), first- and second-order reactions proceed side by side at comparable rates under ordinary conditions of concentration. At higher concentrations of sodium methoxide the second-order process predominates, whilst at lower the first-order reaction assumes control; and we have approximately isolated the separate reactions by suitably choosing the concentrations of the reactants.

A number of second- and first-order velocity constants are summarised in Table I; the details of their determination will be found in the experimental section. In the range of concentration of sodium methoxide 0·5—1·0*M* we obtain good second-order constants. (This does not mean that the reaction is kinetically pure, because the constancy of a velocity constant is not a senstive test for kinetic purity.) The difference between constants for the

0·5*M* and 1·0*M* concentrations of methoxide is an effect of ionic strength, as is shown by the constant for the run carried out in the presence of added sodium bromide. The effect is in the right direction for the bimolecular mechanism: a dense ionic atmosphere must favour the condensation of charges of like sign, and therefore the formation of a transition state between two negative ions such as the methoxide and α-bromopropionate ions.

In the range of concentration *M*/32—*M*/16 we obtain good unimolecular constants. (Again, this does not indicate more than an approximate kinetic purity.) For this first-order reaction the effect of ionic strength works in the opposite direction, as is shown by the constant for the run conducted in the presence of added sodium bromide. We expect this; indeed, it is part of the evidence that the second- and first-order reactions have fundamentally different mechanisms. The rate-controlling stage of the first-order reaction is an ionisation, in the transition state of which the anionic charge becomes divided between the carboxylate group and the bromine atom; and, since a dense ionic atmosphere opposes the sub-division of like charges, it must oppose the formation of such a transition state. The first-order constants obtained in the absence of added sodium bromide vary slightly over the range of concentration *M*/32—*M*/16, and the variation is opposite in direction to the ionic-strength effect, which, however, will be small at such concentrations. This observed variation is due to the circumstance that a little of the second-order reaction is present. Without a more extensive investigation of the ionic-strength effect it is impossible accurately to calculate how much of each reaction accompanies the other at the various concentrations, but we estimate that in the presence of *M*/1-sodium methoxide the second-order reaction constitutes about 95% of the whole change, whereas when the initial concentrations are *M*/32 about 90% of the total change proceeds by way of the first-order reaction.

TABLE I.

Reaction Orders and Rate Constants for Methoxylation of Sodium α-Bromopropionate (NaαBP) *by means of Sodium Methoxide in Methyl Alcohol at* 64·0°.

Approx. initial concns.			2nd-Order k	Approx. initial concns.			1st-Order k
NaαBP.	NaOMe.	NaBr.	(sec.$^{-1}$ g.-mol.$^{-1}$ l.).	NaαBP.	NaOMe.	NaBr.	(sec.$^{-1}$).
M/4	*M*/1	—	8.48×10^{-4}	*M*/32	*M*/32	—	5.33×10^{-5}
M/4	*M*/2	—	5.20×10^{-4}	*M*/32	*M*/16	—	5.77×10^{-5}
M/4	*M*/2	*M*/2	7.93×10^{-4}	*M*/16	*M*/16	—	5.93×10^{-5}
				M/32	*M*/32	*M*/2	3.78×10^{-5}

The optical effect obtaining in the second-order reaction was ascertained by allowing a solution which was 1·01*M* with respect to sodium methoxide and 0·252*M* with respect to sodium α-bromopropionate to undergo reaction at 64° for 18·5 hours. The rotations of the α-bromopropionic acid used and of the methoxy-acid obtained were:

$$(\alpha_D^{20^\circ} +12{\cdot}9^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2H \longrightarrow CH_3{\cdot}CH(OMe){\cdot}CO_2H\ (\alpha_D^{26^\circ} -19{\cdot}8^\circ) \quad . \quad . \quad . \quad (III)$$

Evidently configuration has here been inverted. The rotatory power, $\alpha_D^{20^\circ}$, of optically pure bromo-acid is 49°, whilst that of optically pure methoxy-acid is 93·5°. From these figures it follows that under the conditions specified an optically pure bromo-acid would have given a methoxy-acid with an inverted configuration and with 81% of its full optical activity. Owing to its anionic charge the α-bromopropionate ion does not readily racemise (Wilson, *loc. cit.*), and, of course, the α-methoxypropionate ion must be still more optically stable. Hence we do not expect the figures given for the retention of enantiomeric purity to be appreciably affected by racemisation which is previous or subsequent to the process of substitution. For the same reasons it is unnecessary to correct the experimental result for the incompleteness of conversion.

For the investigation of the first-order reaction we used a solution which was 0·063*M* with respect to sodium α-bromopropionate and 0·077*M* with respect to sodium methoxide, the reaction being allowed to proceed at 64° for 26 hours. The rotations of the bromo-acid used and of the methoxy-acid obtained were:

$$(\alpha_D^{20^\circ} +12{\cdot}9^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2H \longrightarrow CH_3{\cdot}CH(OMe){\cdot}CO_2H\ (\alpha_D^{26^\circ} +17{\cdot}9^\circ) \quad . \quad . \quad (IV)$$

Here there is a retention of configuration, and it can be calculated that an optically pure bromo-acid would have yielded a methoxy-acid with 73% of its maximal activity. Again we do not expect the result to be influenced by the occurrence of racemisation before or after substitution.

Since the optical effects of the second- and first-order reactions are opposite in sign, it follows that our estimates of the percentage retention of enantiomeric purity are rendered too low by the occurrence along with each reaction of a small proportion of the other. Making the most probable estimates of the amounts of these minor reactions, we judge that the retention of optical purity for the second-order reaction is at least 85% with inversion, whilst for the first-order reaction it is at least 90% with retention of configuration.

Mechanism of Methoxylation.—Before leaving the Scheme A, we should mention that the reason why we have used the experimental terminology, "second-order," "first-order," and not the mechanistic nomenclature, "bimolecular," "unimolecular," is that the two sets of terms are interchangeable only for three of the four reactions. The two second-order reactions (I and III) are obviously nucleophilic, bimolecular substitutions (S_N2). The first-order reaction of the bromopropionate anion (IV) is equally certainly unimolecular (S_N1): its speed is far too great to admit of the supposition that it is a bimolecular ("ψ-unimolecular") reaction with solvent methyl alcohol acting as a base; and besides, we have the evidence of the optical behaviour. On the other hand, the very slow first-order substitution in α-bromopropionic ester (II) could be a bimolecular (ψ-unimolecular) reaction with solvent methyl alcohol, and the optical result indicates that it is: this reaction follows mechanism (S_N2), even although it is kinetically of the first order (cf. Part VI).

(B) *Hydroxylation.*

For the experiments on hydroxylation we have used both α-bromopropionic acid and its anion, water being the solvent; when we wished to substitute the carboxylic acid our practice was to add sufficient sulphuric acid largely to suppress the splitting of the bromo-acid into its ions; in experiments designed to substitute the anion we employed sodium α-bromopropionate and operated in the presence of sufficient sodium hydroxide to ensure that the solution would remain alkaline throughout the reaction.

The following scheme summarises the qualitative observations:

SCHEME B.

Hydrolysis of α-Bromopropionic Acid and Sodium α-Bromopropionate.

d-CH_3·CHBr·CO_2H —(First order)→ l-CH_3·CH(OH)·CO_2H . . . . . (V)

↓ (from d-CH_3·CHBr·CO_2H) ↓ (from l-CH_3·CH(OH)·CO_2H)

d-CH_3·CHBr·CO_2^- —(Second order)→ l-CH_3·CH(OH)·CO_2^- . . . . . (VI)

d-CH_3·CHBr·CO_2^- —(First order)→ d-CH_3·CH(OH)·CO_2^- . . . . . (VII)

The symbols d and l signify configuration. The relations with sign of rotation are normal [$d(+)$ and $l(-)$] except for free lactic acid; however, all hydroxylation products were examined for rotatory power in the form of ethyl lactate, for which again the relations are normal.

Reactions V (Acid + Water).—As will be shown in detail later, the anion of α-bromopropionic acid undergoes hydrolysis in aqueous solution considerably more rapidly than does the undissociated acid. It is, therefore, difficult completely to isolate the hydrolysis of the undissociated acid; for even in an acidic solution, in which the concentration of the acid is much greater than that of the anion, some hydrolysis of the latter is liable to occur. We investigated the kinetics and optical characteristics of the hydrolysis of α-bromopropionic acid in 0·5N-aqueous sulphuric acid. This concentration of mineral acid is sufficient to ensure that the hydrolysis of the undissociated acid shall be the principal reaction, even though some hydrolysis of the anion proceeds simultaneously.

Like the acid methyl alcoholysis of the bromo-ester, the acid hydrolysis of the bromo-

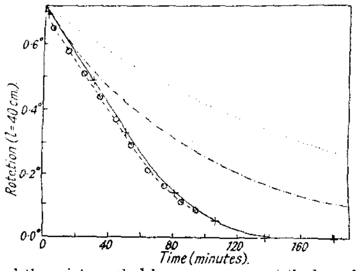
acid is very slow, and we were therefore forced to study it at 100°, although we would have preferred to use some lower temperature for which the ionisation constant of the acid is known. At 100° the reaction is experimentally of the first order, the rate constant being 0·000091 sec.$^{-1}$; the period of half-change is 126 minutes.

A solution 0·098*M* with respect to α-bromopropionic acid and 0·53*N* with respect to sulphuric acid was heated for 50 hours at about 91°, a time amply sufficient to complete the substitution. The lactic acid thus produced was converted into ethyl lactate. The following rotations were observed :

$$(\alpha_D^{25°} + 19\cdot0°)\ CH_3\cdot CHBr\cdot CO_2H \longrightarrow CH_3\cdot CH(OH)\cdot CO_2Et\ (\alpha_D^{23°} - 0\cdot61°) \quad . \quad . \quad (V)$$

Configuration has here been inverted, but with much racemisation. The rotation of optically pure ethyl lactate is $\alpha_D^{19°}$ 11·5° (Wood, Such, and Scarff, J., 1923, 123, 600), and hence a bromo-acid having 39% of its maximal rotation has yielded an ethyl lactate with 5·3% of its full rotation. Optically pure bromo-acid would under the same conditions have given ethyl lactate with an inverted configuration and 14% of its maximal rotatory power.

FIG. 4.



The full-line curve and the points marked by crosses represent the loss of optical activity from a 0·1*M*-solution of α-bromopropionic acid in 0·53*N*-aqueous sulphuric acid at 100°. (The broken line and circles represent another experiment made with a slightly lower initial concentration of bromo-acid.) The dotted curve indicates the fall of activity which would be produced by hydroxylation if the bromopropionic acid did not racemise. The chain-line curve shows how the activity would vary if hydrogen-racemisation were the only mechanism of racemisation. Allowance being made for the bromine-racemisation, we obtain a curve almost coincident with the experimental curve.

We have to decide how much of the loss of optical activity represented by this figure takes place before, and how much during, substitution : none can occur after substitution, since the product, lactic acid, is optically stable under the experimental conditions. We require to know the rate of racemisation of α-bromopropionic acid under the conditions employed for the hydrolysis, and have therefore studied the variation with time of the rotations of sulphuric acid solutions of α-bromopropionic acid. An aqueous solution, 0·099*M* with respect to α-bromopropionic acid and 0·53*N* with respect to sulphuric acid, was kept at 100°; and from time to time samples were withdrawn for the measurement of their rotation at room temperature. The results are shown by the crosses about the full-line curve of Fig. 4. The broken line and the points marked by circles refer to a duplicate experiment with a slightly lower concentration of bromo-acid. It will be seen that the experimental curve has the "hockey-stick" shape encountered previously, although the present curve does not cross the time-axis.

The reason why the curve runs into the time-axis is simply that the specific rotatory power of lactic acid in aqueous solution is so small that, even although this acid is produced with an appreciable fraction of its maximal activity, it contributes practically nothing at any time to the observed rotation of the solution. It can be calculated from the result of the "isolation" experiment recorded above that, even at "infinite" time, the partial

rotation due to lactic acid would be less than 0·01°, which is the error of measurement. Therefore, the curve representing the partial rotation of the bromo-acid may be taken as identical with the experimental curve for the total rotation.

As in the example previously described, the fall of the partial rotation of the bromo-compound arises from three contributing causes. The disappearance of bromo-acid due to hydroxylation would produce an exponential fall of rotation: the known rate constant of this contribution is 0·000091 sec.$^{-1}$ (half-change 126 mins.). The curve showing how the rotation would vary if this effect acted alone is represented by the dotted line in Fig. 4. Fixing attention on the initial stages of reaction, we see that hydroxylation accounts for rather more than half the initial rate of loss of optical activity.

The remainder of the initial rate is due to a first-order racemisation of the bromo-acid itself. This is the reaction which we call "hydrogen-racemisation." In the acid medium we would expect it to be slow, and it is actually somewhat slower than the hydroxylation. From the difference between the *initial* slopes of the experimental rotation–time curve and of the curve which shows how the rotation would fall in the absence of racemisation, we can deduce the rate constant of the hydrogen-racemisation: the value is 0·000083 sec.$^{-1}$ (half-change, 139 mins.).

The hydroxylation and hydrogen-racemisation acting together, but without any third contributory effect, would produce an exponential fall of rotations, the curve for which, drawn from the known rate constants, is shown by a chain-line in Fig. 4. The divergence between this curve and the experimental curve is due to the racemising attack of bromide ions on the bromo-acid, the bromide ions being those liberated in the hydroxylation. This "bromine-racemisation" starts with zero velocity, and its speed then increases, passes through a maximum, and finally decreases again to zero. As explained in the previous instance and illustrated in Fig. 3, it is this special kind of rate-variation which, when combined with the more normal trend of the rates of the substitution and hydrogen-racemisation, leads to the initial straightness of the experimental curve and to the rather sharp turn near the time axis.

We can determine the rate of the bromine-racemisation in either of two ways. For the initial stages of reaction, the divergence between the experimental rotation–time curve and the curve representing the rotations which would be observed in the absence of the bromine-racemisation measures the rate of the bromine-racemisation; and the time-rate of increase of the divergence measures the time-rate of increase of the rate of this process. By comparing this time-rate with the known time-rate of increase of the concentration of the attacking bromide ion, we can find the rate constant: it is 0·0080 sec.$^{-1}$ g.-mol.$^{-1}$ l.

Alternatively, we can employ the theoretical equation, given in the Appendix, for the variation of rotation with time. The equation contains the known rate constants of the hydroxylation and the hydrogen-racemisation, and the required rate constant of the bromine-racemisation; it does not contain a constant representing a ratio of rotatory powers characterising the hydroxylation, because this constant would be required only in order to express the negligible partial rotation of the hydroxylation product. Hence the rate constant for the bromine-racemisation is the only unknown, and a single point on the experimental curve suffices to determine it. Using, *e.g.*, $\alpha = 0{\cdot}15°$ at $t = 80$ mins., we find for the rate constant 0·0080 sec.$^{-1}$ g.-mol.$^{-1}$ l., in agreement with the result given by the other method.

All the rate constants being known, we can plot a curve representing the theoretical course of the change of rotation with time. This curve agrees so closely with that drawn through the experimental points that the two cannot be shown separately in Fig. 4.

We now have all the data necessary to calculate in what proportion optical activity should be retained in the lactic acid formed by complete hydroxylation of α-bromopropionic acid under the conditions of the "isolation" experiment, if the only cause for loss of activity were the racemisation of the bromo-acid (by both mechanisms) in advance of hydroxylation. The answer is 26%. The observed result was an inversion retaining 14% of the possible optical activity. Hence the hydroxylation acting in the absence of any prior racemisation of the bromo-acid would have inverted configuration with a retention of 54% of the maximal optical activity.

Now we shall show later that hydrolysis of the α-bromopropionate ion in the absence of a large excess of alkali leads to a lactic acid which preserves the original configuration and retains practically the whole of the optical activity. Since in the experiments described above a certain amount of the hydroxylation must have taken place by way of the α-bromopropionate ion, it follows that our figure 54% is a minimum value for the retention of activity characterising the inversion which takes place in the hydroxylation of the undissociated acid. If we knew the proportion in which hydrolysis occurred through the anion we could make a correction, and thus quote a precise value instead of a minimum for the proportion of activity retained with inversion in the hydroxylation of the undissociated acid.

An experimental basis for this correction can be obtained by changing the initial concentration of sulphuric acid, and therefore the proportion of reaction which proceeds through the anion, in known ratio, and measuring the corresponding change in the rate of hydrolysis. If, for instance, we halve the concentration of hydrogen ions, the proportion of α-bromopropionic acid which is ionised will be doubled; and therefore the rate of that part of the reaction which proceeds through the α-bromopropionate ion will also be doubled. The increase of rate will thus be equal to the partial rate of hydrolysis of the bromopropionate ions as it stood before the concentration of hydrogen ions was halved; and the ratio of this partial rate to the observed total rate will give the required proportion of reaction which, under those conditions, took place through the anion. This assumes, first, that the fraction of bromopropionic acid which is ionised under the conditions of the comparative experiments is small, as it certainly would be; and secondly, that the mass law is a good approximation. Practically we have to make the calculation in a slightly more complicated way, because hydrobromic acid is liberated in the course of hydrolysis, so that the concentration of hydrogen ions is not quite constant throughout a determination of reaction rate; however, this circumstance is sufficiently allowed for by calculating with mean, rather than initial, hydrogen-ion concentrations.

Two rate determinations were carried out at the same time in the same thermostat at 100°; in each the initial concentration of α-bromopropionic acid was $M/10$; but in the first the concentration of sulphuric acid was 0·491N, whilst in the second it was 0·245N; so that the *average* concentrations of hydrogen ions were 0·541N and 0·296N respectively. This means that in the second experiment the rate of that part of the reaction which proceeds through the anion should have been increased in the ratio 0·541/0·296, *i.e.*, by 83%. The observed mean rates were 0·000100 and 0·000119 sec.$^{-1}$. Attributing the increase, 0·000019 sec.$^{-1}$, to the increased proportion of anion, we calculate that in the first experiment the partial rate of the reaction of the bromopropionate ion was 0·000023 sec.$^{-1}$; whilst by difference the partial rate for the bromopropionic acid molecule was 0·000077 sec.$^{-1}$. Hence the proportion of reaction which proceeded through the anion was 23%. In our experiment with optically active material the mean acidity was a little greater than in the first of the above comparative experiments, and, allowing for this, we find that the proportion of anion hydrolysis in the optical experiment must have been 22%. Assuming that this part of the reaction proceeds exclusively with retention of stereochemical form, it follows from the observed optical effect of the total reaction that the proportion in which optical activity is retained in the inversion which characterises the substitution of the undissociated acid is 97%.

Reactions VI and VII (*Sodium Salt + Sodium Hydroxide*).—When sodium α-bromopropionate is hydrolysed in aqueous solution in the presence of at least one equivalent of sodium hydroxide, second- and first-order hydroxylations proceed side by side at comparable rates under the usual conditions of concentration. Senter originally arrived at this conclusion (J., 1909, **95**, 1827); the re-interpretation of his results proposed by Zawidzki (*Rocz. Chem.*, 1926, **6**, 136; *Z. physikal. Chem.*, 1928, **137**, 72) is incorrect. We have approximately isolated the separate reactions by suitably selecting the concentrations of the reactants.

Some rate constants, applying to aqueous solutions at 64°, are given in Table II, which is abstracted from the more detailed record in the experimental section. The isolation of the second-order reaction is rather incomplete: even in the run with M/1-sodium hydroxide there is something like 20% of first-order reaction, so that the true second-order constant

will be correspondingly lower than that recorded. This effect will be about twice as great in the run with $M/2$-sodium hydroxide, and, as the figures show, the difference between the two disturbances outweighs the ionic-strength effect, and makes the observed constant slightly greater, instead of rather considerably smaller, in the more dilute solution. The isolation of the first-order reaction is more complete, and in the most dilute solutions the amount of accompanying second-order process cannot be more than a few units per cent.

TABLE II.

Reaction Orders and Rate Constants for Hydroxylation of Sodium α-Bromopropionate (NaαBP) *by Means of Aqueous Sodium Hydroxide at* 64·0°.

Approx. initial concns.		2nd-Order k	Approx. initial concns.		1st-Order k
NaαBP.	NaOH.	($sec.^{-1}$ g.-$mol.^{-1}$ l.).	NaαBP.	NaOH.	($sec.^{-1}$).
$M/4$	$M/1$	$6{\cdot}35 \times 10^{-4}$	$M/32$	$M/32$	$1{\cdot}18 \times 10^{-4}$
$M/4$	$M/2$	$6{\cdot}7 \times 10^{-4}$	$M/32$	$M/16$	$1{\cdot}19 \times 10^{-4}$
			$M/16$	$M/16$	*ca.* $1{\cdot}23 \times 10^{-4}$ *
			$M/10$	$M/10$	*ca.* $1{\cdot}3 \times 10^{-4}$ *

* Values fall during run.

The optical effect in the second-order reaction was investigated by allowing a solution, $0{\cdot}250M$ with respect to sodium α-bromopropionate and $1{\cdot}00M$ with respect to sodium hydroxide, to undergo reaction at 64° for 3 hours; the lactic acid formed was converted into ethyl lactate. The following rotations were observed :

$$(\alpha_D^{18\cdot5^\circ} +19{\cdot}1^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2H \longrightarrow CH_3{\cdot}CH(OH){\cdot}CO_2Et\ (\alpha_D^{26^\circ} -2{\cdot}26^\circ) \quad . \quad . \quad (VI)$$

These figures mean that configuration is inverted, and that a bromo-acid with 39% of its maximal rotation has given an ethyl lactate with 20% of its maximal rotation; with optically pure bromo-acid the retention of activity in the ethyl lactate would be 51%. For reasons similar to those given in connexion with the methoxylation of sodium α-bromopropionate, we do not expect any appreciable disturbance from racemisation before or after the substitution, and therefore no correction is necessary for the incompleteness of substitution.

For the optical examination of the first-order reaction we allowed a solution, $0{\cdot}065M$ with respect both to sodium α-bromopropionate and to sodium hydroxide, to undergo reaction at 64° for 16·25 hours. The rotations were :

$$(\alpha_D^{18\cdot5^\circ} +19{\cdot}1^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2H \longrightarrow CH_3{\cdot}CH(OH){\cdot}CO_2Et\ (\alpha_D^{26^\circ} +3{\cdot}12^\circ) \quad . \quad . \quad (VII)$$

There is here a retention of configuration, and optically pure bromo-acid would have yielded an ethyl lactate with 70% of its full activity. These figures also should be unaffected by any appreciable racemisation prior to or following the substitution.

When we make the most probable allowances for the minor proportion in which each reaction must accompany the other in these experiments, we find that the retention of optical purity in the second-order process must amount to 80—100% with inversion, whilst for the *first-order reaction it must be 85—100% with retention of configuration.*

Mechanism of Hydroxylation.—Concerning the interpretation of the Scheme B, the second-order substitution of the anion is obviously bimolecular in mechanism (S_N2), and the first-order substitution of the anion is proved by its high speed and by the optical result to be unimolecular (S_N1). The slow first-order substitution of the undissociated acid might *a priori* be either a unimolecular reaction or a bimolecular (ψ-unimolecular) substitution with solvent water acting as a basic reagent. The optical result indicates that the reaction is actually bimolecular (S_N2), even though it is of the first order (cf. Part VI).

SUMMARY

(Covering Parts I, II, and III).

The principal conclusions reached in this paper are summarised in Table III, in which the results recorded in Parts I and II are included for convenience. The first col. indicates the paper of this series in which the details are to be found. The next four cols., which contain respectively the formula of the compound substituted, the substitution process, the

solvent, and the temperature, require no explanation. Under the heading "reagent" is inserted, for the S_N2-reactions, the molecule or ion which enters along with the halogen compound into the bimolecular process; but, for the S_N1-reactions, the entries represent the molecule from which, after the rate-determining step has been accomplished, the substituent is derived. A distinction is made in the next two cols. between reaction order and mechanism: the "order" represents the experimental kinetic result; and a second-order reaction always corresponds to a bimolecular mechanism, whereas a first-order reaction may signalise either a bimolecular or a unimolecular mechanism, according to the criteria given in the preceding detailed discussion. The penultimate col. contains a qualitative statement of the effect of the substitution on configuration (Ra = racemisation; Re = retention; I = inversion), and the last col. the proportionate retention of optical purity associated with the inversion or retention of configuration. Figures such as 96% and 94% may be regarded as scarcely distinguishable in practice from 100%. If the retention of optical purity is p%, the proportion of the major enantiomeride is the greater quantity $\frac{1}{2}(p + 100)$%.

TABLE III.

Relation of Optical Effect to Kinetics and Mechanism of Substitution.

Paper.	Halide subsd.	Subsn. process.	Solvent.	Ap-prox. temp.	Re-agent.	Reaction. Or-der.	Reaction. Mech-anism.	Effect on configtn.	Reten-tion of optical purity, %.
I	C_6H_{13}, CH_3, H >C·Br	Hydroxylation	60% aq. EtOH	80°	OH^-	2	S_N2	I	96
					H_2O	1	S_N1	Ra + I	66
		Ethoxylation	,,	80	OEt^-	2	S_N2	I	96
					HOEt	1	S_N1	Ra + I	74
		,,	Anhydr. EtOH	80	OEt^-	2	S_N2	I	~100
	C_6H_{13}, CH_3, H >C·Cl	,,	,,	80	OEt^-	2	S_N2	,,	~100
II	C_6H_5, CH_3, H >C·Cl	Hydroxylation	H_2O	20	H_2O	—	S_N1	Ra + I	17
			60% aq.-Me_2CO	70	H_2O	1	S_N1	,,	5
			80% aq.-Me_2CO	70	H_2O	1	S_N1	,,	2
		Methoxylation	Anhydr. MeOH	70	OMe^-	2	S_N2	I	(high)
			,,	70	HOMe	1	S_N1	Ra + I	(low)
		Ethoxylation	Anhydr. EtOH	70	OEt^-	2	S_N2	I	(high)
			,,	70	HOEt	1	S_N1	Ra + I	(low)
	C_6H_5, CH_3, H >C·Br	Hydroxylation	H_2O	20	H_2O	—	S_N1	,,	(low)
III	CO_2H, CH_3, H >C·Br	Hydroxylation	Dil. aq.-H_2SO_4	90	H_2O	1	S_N2	I	~100
	CO_2Me, CH_3, H >C·Br	Methoxylation	Anhydr. MeOH	25	OMe^-	2	S_N2	,,	~100
				100	HOMe	1	S_N2	,,	~100
	CO_2^-, CH_3, H >C·Br	Hydroxylation	H_2O	64	OH^-	2	S_N2	,,	80—100
					H_2O	1	S_N1	Re	90—100
		Methoxylation	Anhydr. MeOH	64	OMe^-	2	S_N2	I	85—100
					HOMe	1	S_N1	Re	90—100

A more condensed statement of the main outcome can be given, because, as Table III clearly shows, the qualitative results are independent of the halogen which is replaced

TABLE IV.

Steric Course of the Homogeneous Replacement of ·Hal by ·OR.

R in CHMeR·Hal.	Effect on configuration. Mechanism S_N2.	Effect on configuration. Mechanism S_N1.
C_6H_{13}	Inversion	Racemisation + inversion
C_6H_5	,,	Large racemisation + inversion
CO_2H, CO_2Me	,,	(Not known)
CO_2^-	,,	Retention

Note.—Racemisation accompanying inversion is increased by dilution of the hydroxylic solvent with a non-hydroxylic solvent.

(chlorine or bromine), and of the group which replaces it (hydroxyl, methoxyl, or ethoxyl). The short summary thus made possible is given in Table IV, which will be understood to refer only to *homogeneous* mechanisms of substitution : there are well-known heterogeneous methods of effecting the replacement of halogen by hydroxyl and alkoxyl, and we have still to present our data concerning the steric course of these (see Parts IV and V).

APPENDIX.

The Polarimetric Rate Equations.

(1) *Equation for the rotation–time curve for methyl α-bromopropionate in methyl-alcoholic sodium methoxide* (*Reaction I*; *see Fig.* 1). The following symbols are defined :

α = Observed rotation = $\alpha_B + \alpha_M$.
α_B = Partial rotation due to bromo-ester.
α_M = ,, ,, ,, ,, methoxy-ester.
θ_B = " Rotatory power " of bromo-ester defined by $\alpha_B = \theta_B c_B$.
θ_M = ,, ,, ,, methoxy-ester ,, ,, $\alpha_M = \theta_M c_M$.
c_B = Concentration of bromo-ester = concentration of methoxide ions.
c_M = Concentration of methoxy-ester.
t = Time from commencement of reaction.
α_0 = Value at zero-time of α = value at zero-time of α_B.
θ_0, c_0 = Values at zero-time of θ_B and c_B.
θ_{B1} = Value at time $t = t_1$ of θ_B.
α_{M2} = Value at time $t = t_2$ of α_M.
$\delta\alpha_{M11}$ = Partial rotation at $t = t_1$ due to small increment of methoxy-ester formed at $t = t_1$.
$\delta\alpha_{M12}$ = Partial rotation at $t = t_2$ due to small increment of methoxy-ester formed at $t = t_1$.
θ'_{M11} = Rotatory power at $t = t_1$ of increment formed at $t = t_1$; defined by $\delta\alpha_{M11} = \theta'_{M11}\delta c_{M1}$.
θ'_{M12} = Rotatory power at $t = t_2$ of increment formed at $t = t_1$; defined by $\delta\alpha_{M12} = \theta'_{M12}\delta c_{M1}$.
δc_{B1} = Increment of concentration of bromo-ester destroyed at $t = t_1$.
δc_{M1} = ,, ,, ,, ,, methoxy-ester formed at $t = t_1$.
δt_1 = Increment of time used in producing the increment of concentration $\delta c_{M1} = -\delta c_{B1}$.
k_{2BH} = Second-order rate constant for catalysed hydrogen-racemisation of bromo-ester.
k_{2MH} = ,, ,, ,, ,, ,, ,, ,, ,, methoxy-ester.
k_{2S} = ,, ,, ,, ,, ,, substitution process.
χ = Constant defined by $\theta'_{M11} = \chi\theta_{B1}$ and assumed independent of time. The constant χ is the required ratio of rotatory powers characteristic of the substitution.

By definition

$$\alpha = \theta_B c_B + \theta_M c_M \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The factors in the first term on the right-hand side can be separately calculated. The differential equation for c_B is

$$-(dc_B/dt) = k_{2S}c_B{}^2 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

which on integration gives

$$c_B = c_0(1 + c_0k_{2S}t)^{-1} \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The differential equation for θ_B is

$$-(d\theta_B/dt) = k_{2BH}\theta_B c_B$$

Substituting for c_B by means of equation (3) and integrating, we find

$$\theta_B = \theta_0(1 + c_0k_{2S}t)^{-k_{2BH}/k_{2S}} \quad . \quad . \quad . \quad . \quad . \quad (4)$$

From equations (3) and (4) we have for the first term in α

$$\alpha_B = \theta_B c_B = \alpha_0(1 + c_0k_{2S}t)^{-(k_{2BH}+k_{2S})/k_{2S}} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

In order to evaluate the second term, we first calculate the partial rotation $\delta\alpha_{M11}$ of an increment of methoxy-ester freshly formed at time t_1. We have

$$\delta\alpha_{M11} = \theta'_{M11}\delta c_{M1} = \chi\theta_{B1}(-\delta c_{B1}) = \chi\theta_{B1}k_{2S}c_{B1}{}^2\delta t_1$$

in which use has been made of equation (2). Substituting for θ_{B1} and c_{B1} with the aid of equations (4) and (3) respectively, we find

$$\delta\alpha_{M11} = \theta'_{M11}\delta c_{M1} = \chi k_{2S}\theta_0 c_0{}^2(1 + c_0k_{2S}t_1)^{-(k_{2BH}+2k_{2S})/k_{2S}}\delta t_1 \quad . \quad . \quad . \quad (6)$$

The next step is to obtain the relation between θ'_{M11} and θ'_{M12}, so that we can evaluate *the partial rotation* $\delta\alpha_{M12}$ *of the same increment at a later time* t_2. The differential equation for θ'_{M1t} is

$$-(d\theta'_{M1t}/dt) = k_{2MH}\theta'_{M1t}c_B$$

Substituting for c_B by means of equation (3) and integrating from t_1 to t_2, we find

$$\frac{\theta'_{M12}}{\theta'_{M11}} = \left(\frac{1 + c_0k_{2S}t_2}{1 + c_0k_{2S}t_1}\right)^{-k_{2MH}/k_{2S}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

Combination of equations (6) and (7) gives

$$\delta\alpha_{M12} = \theta'_{M12}\delta c_{M1} = \chi k_{2S}\theta_0c_0{}^2(1 + c_0k_{2S}t_1)^{-(k_{2BH}-k_{2MH}+2k_{2S})/k_{2S}}(1 + c_0k_{2S}t_2)^{-k_{2MH}/k_{2S}}\delta t_1 \quad (8)$$

The partial rotation due to the whole of the methoxy-ester present at the time t_2 is obtained *by integrating the coefficient of* δt_1 *in equation (8) with respect to* dt_1 between the limits $t_1 = 0$ and $t_1 = t_2$:

$$\alpha_{M2} = \chi k_{2S}\theta_0c_0{}^2(1 + c_0k_{2S}t_2)^{-k_{2MH}/k_{2S}}\int_{t_1=0}^{t_1=t_2}(1 + c_0k_{2S}t_1)^{-(k_{2BH}-k_{2MH}+2k_{2S})/k_{2S}}dt_1$$

Evaluating the integral, and dropping the now unnecessary subscript from t_2, we find

$$\alpha_M = \theta_Mc_M = \chi\theta_0c_0 \cdot \frac{k_{2S}}{k_{2BH} - k_{2MH} + k_{2S}} \cdot \left\{(1 + c_0k_{2S}t)^{-k_{2MH}/k_{2S}} - (1 + c_0k_{2S}t)^{-(k_{2BH}+k_{2S})/k_{2S}}\right\} \; (9)$$

By adding equations (5) and (9), we obtain the complete expression for α:

$$\alpha = \alpha_0\left[(1 + c_0k_{2S}t)^{-(k_{2BH}+k_{2S})/k_{2S}} + \chi \cdot \frac{k_{2S}}{k_{2BH} - k_{2MH} + k_{2S}} \cdot \left\{(1 + c_0k_{2S}t)^{-k_{2MH}/k_{2S}} - (1 + c_0k_{2S}t)^{-(k_{2BH}+k_{2S})/k_{2S}}\right\}\right] \quad . \quad (10)$$

The constants k_{2MH} *and* k_{2S} *are independently evaluated.* The constants k_{2BH} and χ have to be obtained by fitting the equation to the experimental results. Note that, since the substitution involves inversion in the sign of rotation, χ is negative.

(2) *Equation for the rotation–time curve for methyl α-bromopropionate in methyl alcohol (Reaction II; see Fig. 2).* Here the racemisation of the methoxy-ester may be neglected, but an additional process of racemisation of the bromo-ester, due to the attack of bromide ions, has to be taken into account.

The symbols α, α_B, α_M, θ_B, θ_M, t, α_0, θ_0, c_0, are defined as before; and in addition we set:

c_B = Concentration of bromo-ester.
c_M = ,, ,, methoxy-ester.
$\delta\alpha_M$ = Partial rotation of small increment of methoxy-ester.
θ'_M = Rotatory power ,, ,, ,, ,, ,, , defined by $\delta\alpha_M = \theta'_M\delta c_M$.
δc_B = Increment of concentration of bromo-ester.
δc_M = ,, ,, ,, ,, methoxy-ester.
δt = ,, ,, time used in producing the increments $\delta c_M = -\delta c_B$.
k_{1BH} = First-order rate constant for hydrogen-racemisation of bromo-ester.
k_{2BB} = Second- ,, ,, ,, ,, bromine- ,, ,, ,,
k_{1S} = First- ,, ,, ,, ,, substitution (methoxylation) process.
χ = Constant defined by $\theta'_M = \chi\theta_B$, where θ'_M and θ_B refer to the same time; χ is assumed to be independent of time.

Evaluating the separate terms of equation (1) as before, we find for c_B

$$-(dc_B/dt) = k_{1S}c_B \quad . \quad . \quad . \quad (11)$$

$$c_B = c_0 e^{-k_{1S}t} \quad . \quad . \quad . \quad (12)$$

The differential equation for θ_B is

$$-(d\theta_B/dt) = k_{1BH}\theta_B + k_{2BB}\theta_B c_M$$
$$= k_{1BH}\theta_B + k_{2BB}\theta_B(c_0 - c_B)$$

Substituting for c_B from equation (12) and integrating, we find

$$\theta_B = \theta_0 \exp\left\{-(k_{1BH} + k_{2BB}c_0)t + \frac{k_{2BB}c_0}{k_{1S}}(1 - e^{-k_{1S}t})\right\} \quad . \quad . \quad . \quad (13)$$

Combining equations (12) and (13), we have for the partial rotation of bromo-ester

$$\alpha_B = \alpha_0 \exp\left\{-(k_{1S} + k_{1BH} + k_{2BB}c_0)t + \frac{k_{2BB}c_0}{k_{1S}}(1 - e^{-k_{1S}t})\right\} \quad . \quad . \quad (14)$$

The partial rotation of methoxy-ester, α_M, is an integral from 0 to t of $d\alpha_M$. We have $\delta\alpha_M = \theta'_M\delta c_M$, $\theta'_M = \chi\theta_B$, and $\delta c_M = -\delta c_B$; and using equation (11), we obtain

$$\alpha_M = \int\theta'_M dc_M = -\chi\int\theta_B dc_B = \chi k_{1S}\int\theta_B c_B dt = \chi k_{1S}\int\alpha_B dt$$

Taking account of equation (14), we have

$$\alpha_M = \chi\alpha_0 k_{1S}\int_0^t \exp\left\{-(k_{1S} + k_{1BH} + k_{2BB}c_0)t + \frac{k_{2BB}c_0}{k_{1S}}(1 - e^{-k_{1S}t})\right\}dt \quad . \quad (15)$$

The exact equation for the rotation–time curve is obtained by addition of equations (14) and (15), but, for application over the range experimentally studied, the following approximate equations are good to within about 1%. In equation (14) we must expand the internal exponential as far as the term in t^3:

$$\alpha_B = \alpha_0 \exp\{-(k_{1S} + k_{1BH})t - \tfrac{1}{2}k_{1S}k_{2BB}c_0t^2(1 - \tfrac{1}{3}k_{1S}t)\} \quad . \quad . \quad . \quad (16)$$

In equation (15) the inner exponential need be expanded only as far as the term in t^2:

$$\alpha_M = \chi\alpha_0 k_{1S}\int_0^t \exp\{-(k_{1S} + k_{1BH})t - \tfrac{1}{2}k_{1S}k_{2BB}c_0t^2\}dt$$
$$= \chi\alpha_0 k_{1S} \exp\left\{\frac{(k_{1S} + k_{1BH})^2}{2k_{1S}k_{2BB}c_0}\right\}\int_0^t \exp\left\{-\tfrac{1}{2}k_{1S}k_{2BB}c_0\left(t + \frac{k_{1S} + k_{1BH}}{k_{1S}k_{2BB}c_0}\right)^2\right\}dt \quad . \quad (17)$$

The definite integral in (17) is an "error function," the values of which can be found in tables. The approximate equation for the rotation–time curve is the sum of equations (16) and (17).

(3) *Equation for the rotation–time curve for α-bromopropionic acid in aqueous sulphuric acid* (*Reaction V*; *see Fig.* 4). The previous definitions of symbols apply, except that, as they now relate to the bromo-acid and hydroxy-acid instead of the bromo-ester and methoxy-ester, we should replace the subscript M by H. With this change the formulæ of the preceding section hold good; but, since α_H (the old α_M) is experimentally inappreciable, the right-hand side of equation (14) is a sufficiently accurate expression for α.

Experimental.

Methyl d- *and* l-*Lactate*.—The stock of *d*-lactic acid was a crude, dark syrup supplied many years ago by Messrs. Panton Ltd. to Sir William Ramsay. It was dehydrated at 110° under reduced pressure, and then esterified (420 c.c.) by boiling with methyl alcohol (2200 c.c.) for 4 hours under reflux. (It was not necessary to add a mineral acid.) After evaporation of the methyl alcohol, the residue yielded almost optically pure methyl *d*-lactate (240 g.), b. p. 46°/10 mm., $\alpha_D^{20°}$ (l = 20 cm.) +16·07°. Methyl *l*-lactate was prepared from a commercial sample of lactic acid (250 c.c.), which yielded an ester (88 g.) having b. p. 46°/10 mm., $\alpha_D^{20°}$ (l = 20 cm.) −11·5°, together with head and tail fractions of lower rotation.

Methyl d- *and* l- *and* dl-*Bromopropionate*.—The *l*-bromo-ester was prepared from the above

methyl *d*-lactate (111 g.) and phosphorus pentabromide (460 g.) (cf. Walker, J., 1895, **67**, 921). A solution of the ester in chloroform (165 c.c.) was added very slowly to a mixture of the pentabromide and chloroform (100 c.c.). After the violent reaction had subsided the mixture was warmed to complete the solution of the pentabromide, cooled, and poured on to ice. When this decomposition, which must be carefully controlled, was complete, the chloroform layer was separated, shaken with thiosulphate, dried by means of sodium sulphate, and evaporated. The ester was distilled, shaken in ethereal solution with an aqueous suspension of calcium carbonate, recovered, and again distilled. It had b. p. 44°/12 mm., $\alpha_D^{20°}$ −68·57°.

The *d*-bromo-ester was prepared by adding methyl *l*-lactate (71 g.) to phosphorus tribromide (184 g.) in the cold, the reaction being conducted at as low a temperature as possible and completed by very slow warming. The mixture was decomposed by means of ice. The ester, isolated in the normal way (58 g.), had b. p. 46°/14 mm., $\alpha_D^{23°}$ 19·74° (Found : Br, 47·4. Calc. : Br, 47·8%). In other experiments, in which the reaction was allowed longer to go in the cold before warming, 76 g. of methyl lactate and 199 g. of phosphorus pentabromide gave 62 g. and 63 g. of methyl *l*-bromopropionate, b. p. 53°/19 mm., $\alpha_D^{21°}$ −28·87 and −29·05° (Found : C, 29·1; H, 4·3; Br, 47·2. Calc. : C, 28·7; H, 4·2; Br, 47·8%).

The *dl*-bromo-ester was prepared by heating α-bromopropionic acid (40 g.) with methyl alcohol (160 g.) in the presence of concentrated sulphuric acid (8 c.c.) under reflux for 4 hours. The ester, 38 g., had b. p. 56·5°/21 mm.

Methyl l-*α-Methoxypropionate*.—This was prepared by Purdie and Walker's method (J., 1899, **75**, 485) from the above methyl *l*-lactate (87·5 g.), methyl iodide (178 g.), and silver oxide (146 g.). The product, collected in ether and distilled, yielded 62 g. of methoxy-ester, b. p. 41—42°/18 mm., and this on further fractionation gave 44 g. of pure material, b. p. 32—33°/12 mm., $\alpha_D^{20°}$ −53·7°.

Course of Hydrolysis of Ethyl α-Chloropropionate and α-Bromopropionate.—Ethyl *dl*-α-chloropropionate (2·505 g.), dissolved in acetone (55 c.c.), was mixed with 0·926*N*-aqueous potassium hydroxide (39·90 c.c.), and the whole was made up to 100 c.c. with acetone, and kept at 30·0°, portions of 5 c.c. being removed for titration with 0·0950*N*-aqueous hydrochloric acid. After 45 and 270 mins. the titres were 16·15 and 11·85 c.c., the latter value representing the disappearance of 1 mol. of potassium hydroxide. At 270 mins., 5 c.c. of the solution were mixed with water and extracted with ether, and the aqueous solution was examined for halide ions, which were absent.

Ethyl *dl*-α-bromopropionate was investigated in a similar way. Almost immediately after the solution of the ester and potassium hydroxide in aqueous acetone had been made up at 30°, a sample withdrawn for titration showed that 1 mol. of potassium hydroxide had been consumed. However, the solution contained no bromide ions.

Course of the Hydrolysis of α-Chloropropionamide.—The amide was prepared by shaking the methyl ester (30 g.) with concentrated aqueous ammonia (30 c.c.) for 12 hours. The solution thus obtained was evaporated in a vacuum over concentrated sulphuric acid, and the residue was sublimed under reduced pressure and crystallised from light petroleum. A solution of the amide (1·343 g., m. p. 82—83°) in water was mixed with 0·926*N*-aqueous potassium hydroxide and made up to 100 c.c. with water. After 3 hours at 30° no halide ion was liberated, although the solution was 0·117*N* with respect to ammonia, this concentration corresponding to an almost complete hydrolysis of the amide group.

Hydrolysis of Methyl d-*α-Bromopropionate*.—The ester (47 g.), $\alpha_D^{23°}$ +19·74°, was shaken with a solution of potassium hydroxide (32 g.) in water (250 c.c.) until it dissolved (a few minutes), and the solution was extracted with ether, acidified with 6*N*-aqueous sulphuric acid, saturated with sodium chloride, and extracted with ether thoroughly. The second extract was dried with sodium sulphate, and the acid which it yielded was distilled (40 g.), b. p. 102—104°/15—16 mm., $\alpha_D^{20°}$ +12·9° (Found : C, 23·9; H, 3·3; Br, 51·8. Calc. : C, 23·5; H, 3·3; Br, 52·2%). In other experiments 62 g. of ester, $\alpha_D^{21°}$ +28·87°, gave 48 g. of acid, b. p. 84°/3 mm., $\alpha_D^{18·5°}$ +19·12°, and 40 g. of ester $\alpha_D^{23°}$ +29·0° gave 36·4 g. of acid, b. p. 78°/1 mm., $\alpha_D^{25°}$ +19·00°.

Hydrolysis of Methyl l-*α-Methoxypropionate*.—A solution of the ester (20 g.), $\alpha_D^{20°}$ −53·7°, and potassium hydroxide (15 g.) in water (100 c.c.) was kept at room temperature for 3 hours, neutralised, concentrated to 75 c.c. in an open basin, acidified with dilute sulphuric, and extracted 15 times with ether. The crude acid (18 g.) on distillation yielded a pure product (11·6 g.), b. p. 106°/20 mm., $\alpha_D^{20°}$ −52·83°.

Rate of Reaction between Sodium Methoxide and Methyl dl-*α-Bromopropionate in Methyl Alcohol at* 25·0°.—The methyl alcohol was dried by means of magnesium.

(i) The methyl-alcoholic sodium methoxide was standardised by titration with 0·4899*N*-

sulphuric acid : 25 c.c. required 25·90 c.c. with methyl-orange as indicator, and 29·95 c.c. with lacmoid, the end-points being rather indefinite; NaOMe = 0·409*N*. A solution of the bromo-ester in methyl alcohol was mixed with 147 c.c. of the sodium methoxide solution, and the whole made up to 250 c.c. at 25·0°. Samples of 10 c.c. were used for each titration with ammonium thiocyanate after addition of silver nitrate. The reading at ∞_1 was obtained after heating at 25° for 24 hours and then at 64° for 4·5 hours, and that at ∞_2 after adding an equal volume of sodium methoxide solution and heating at 64° for 1 hour.

(ii) *Owing to the unsatisfactory nature of the end-points obtained in the titration of sodium* methoxide in the presence of water, the titrations in this experiment were carried out by using a solution of hydrogen chloride in anhydrous methyl alcohol. This was standardised against silver nitrate. A solution of the bromo-ester (10·00 g.) in methyl alcohol was mixed with 181 c.c. of 0·662*N*-methyl-alcoholic sodium methoxide, and made up to 250 c.c. with methyl alcohol at 25°. The initial concentration of sodium methoxide was found by adding 10·00 c.c. of the reaction solution to 25·00 c.c. of 0·2317*N*-hydrogen chloride in methyl alcohol, and titrating with 0·2290*N*-sodium methoxide with the addition of solid methyl-orange as indicator : required 4·80 c.c.

The results of expts. (i) and (ii) are typical of those on which we rely for the statements in the introduction concerning the kinetics of this reaction. In Table IVA, *a* is the initial concentration of sodium methoxide and *b* that of the bromo-ester; and the bromide-ion concentration and $a - x$ and $b - x$ are expressed in c.c. of 0·1120*N*-bromide per 10 c.c. of solution. The rate constants k_2 are in min.$^{-1}$ g.-mol.$^{-1}$ l.

TABLE IVA.

Expt. (i).					Expt. (ii).				
t (min.).	[Br⁻].	$a - x$.	$b - x$.	10^2k_2.	*t* (min.).	[Br⁻].	$(a - x)$.	$(b - x)$.	10^2k_2.
0·0	0·50	19·45	20·12	—	0·0	0·77	41·90	19·29	—
10·1	1·57	18·38	19·05	2·43	6·0	2·12	40·55	17·94	2·61
20·0	2·55	17·40	18·07	2·61	10·5	3·11	39·56	16·95	2·68
30·1	3·23	16·72	17·39	2·46	16·0	4·07	38·60	15·99	2·60
45·0	4·25	15·70	16·37	2·39	21·5	5·10	37·57	14·96	2·66
60·0	5·05	14·90	15·57	2·20	29·0	6·19	36·48	13·87	2·61
75·1	5·90	14·05	14·72	2·29	36·0	7·16	35·51	12·90	2·60
100·0	7·05	12·90	13·57	2·21	45·2	8·27	34·40	11·79	2·58
140·0	8·55	11·40	12·07	2·21	56·0	9·44	33·23	10·62	2·58
173·5	9·50	10·45	11·12	2·18	69·2	10·67	32·00	9·39	2·57
210·0	10·40	9·55	10·22	2·16	85·2	11·83	30·84	8·23	2·53
272·0	11·60	8·35	9·02	2·12	113·0	13·53	29·14	6·53	2·52
350·0	12·70	7·25	7·92	2·08	130·0	14·27	28·40	5·79	2·48
422·0	13·52	6·43	7·10	1·99	150·0	15·10	27·57	4·96	2·47
480·0	14·05	5·90	6·57	1·98	182·7	16·12	26·55	3·94	2·44
540·0	14·50	5·45	6·12	2·03	215·5	16·79	25·88	3·27	2·37
"∞_1"	19·95	0·00	0·67	—	"∞"	20·06	22·61	0·00	—
"∞_2"	20·62	—	0·00	—					

Expt. (i): (a = 0·2178*N*; b = 0·2253*N*.)

Expt. (ii): (a = 0·4692*N*; b = 0·2160*N*.) ($a - b$ = 0·2532*N*.)

Action of Sodium Methoxide on Methyl l-α-*Bromopropionate in Methyl Alcohol at* 25°.—A solution of the bromo-ester (19·952 g.), $\alpha_D^{20°}$ −53·2°, in methyl alcohol was added to 1·692*N*-methyl-alcoholic sodium methoxide (70·6 c.c.), and the whole was made up to 250 c.c., and heated at 25·0° for 19·0 hours. After neutralisation with methyl-alcoholic hydrogen chloride, the bulk of the solvent was removed with the use of a column, and the methoxy-ester (6·0 g.) was isolated by many extractions with ether after the addition of water. It had b. p. 31°/10 mm., 129°/760 mm., $\alpha_D^{20°}$ (l = 2·5 cm.) +0·49° (Found : C, 50·5; H, 8·8. Calc. : C, 50·8; H, 8·5%).

Action of Sodium Methoxide on Methyl d-α-*Bromopropionate in Methyl Alcohol at* 25°.—A solution of the bromo-ester (38·56 g.), $\alpha_D^{21°}$ +32·17°, in 0·3200*N*-methyl-alcoholic sodium methoxide (722 c.c.) was mixed with methyl alcohol (200 c.c.), and kept at 25·0° for 70·0 hours. The methoxy-ester (10·4 g.) had b. p. 52°/40 mm., 129—130°/760 mm., $\alpha_D^{21°}$ −1·06°. There was no indication of the formation of methyl acrylate, and, in particular, the methyl alcohol removed by distillation did not respond to a test with bromine for the presence of an olefin.

Racemisation of Methyl α-Bromopropionate in Methyl-alcoholic Sodium Methoxide at 25·0°.—A solution (i) of the bromo-ester (4·2456 g.), $\alpha_D^{23°}$ +19·74°, in methyl alcohol was made up to 25 c.c. at 25°. A solution (ii) of 1·047*N*-methyl-alcoholic sodium methoxide (24·30 c.c.) was made up to 25 c.c. at 25°. A solution (iii) prepared from (i) (10 c.c.) and methyl alcohol (10 c.c.) was examined polarimetrically. A solution (iv) prepared from (i) (10 c.c.) and (ii) (10 c.c.) was well shaken, quickly put into the jacketed polarimeter tube at 25°, and examined polarimetrically

at known times. In Table V the time of the first reading on (iv) is treated as the time zero, but the time of commencement of the reaction is estimated from the reading on (iii) as 54 seconds earlier. As shown in the introduction, more than 95% of the change of rotatory power is due to the second-order racemisation of the bromo-ester, for which the rate constant is 0·888 min.$^{-1}$ g.-mol.$^{-1}$ l. (see Fig. 1, p. 1211).

TABLE V.

($\alpha_D^{25°}$ refers to l = 20 cm.)

	Time, min.	Time, sec.	$\alpha_D^{25°}$.	Time, min.	Time, sec.	$\alpha_D^{25°}$.	Time, min.	Time, sec.	$\alpha_D^{25°}$.
Soln. (iii)	—	—	+2·12°	3	17	+0·25°	9	4	−0·08°
Soln. (iv)	0	0	+1·45	3	44	+0·20	9	59	−0·06
	0	29	+1·14	4	19	+0·14	11	7	−0·07
	0	48	+0·94	5	0	+0·08	12	10	−0·07
	1	15	+0·76	5	41	+0·04	20	0	−0·07
	1	33	+0·61	6	9	+0·03	30	0	−0·08
	2	2	+0·50	7	16	±0·00	150	0	−0·10
	2	40	+0·34	8	12	−0·03			

Racemisation of Methyl α-Methoxypropionate in Methyl-alcoholic Sodium Methoxide at 24·7°.—The ester (2·9719 g. at 25°), $\alpha_D^{20°}$ −53·7°, was mixed with 1·692N-methyl-alcoholic sodium methoxide (14·90 c.c. at 25°), and the mixture made up to 25 c.c. with methyl alcohol at 25°. After being kept for 15 min. in the thermostat, the solution was transferred to the jacketed polarimeter tube (24·7° throughout the run). The readings of rotation are in Table VI. The logarithms of the rotations give a rectilinear plot against the time. The first-order rate constant is 4·85 × 10^{-4} min.$^{-1}$, and, as the sodium methoxide is 1·007N, this corresponds to a second-order rate constant 4·82 × 10^{-4} min.$^{-1}$ g.-mol.$^{-1}$ l.

TABLE VI.

($\alpha_D^{25°}$ refers to l = 20 cm.)

t, min.	$\alpha_D^{25°}$.	t, min.	$\alpha_D^{25°}$.	t, min.	$\alpha_D^{25°}$.	t, min.	$\alpha_D^{25°}$.
0	−8·27°	275	−7·11°	536	−6·21°	1665	−3·61°
23	−8·15	305	−6·98	566	−6·10	1752	−3·47
37	−8·09	320	−6·92	1376	−4·14	1823	−3·36
54	−8·01	416	−6·61	1448	−4·01	1895	−3·22
67	−7·95	446	−6·51	1508	−3·90	1958	−3·14
155	−7·52	473	−6·41	1605	−3·73	2000	−3·07
215	−7·30						

Rate of Reaction between Methyl dl-*α-Bromopropionate and Methyl Alcohol at* 100°.—A solution of the bromo-ester (16·0 g.) was made up to 160 c.c. in dry methyl alcohol, and portions of 10 c.c. were sealed up in glass bulbs, which were heated in pairs for known lengths of time at 100°. The course of the reaction was followed by determining the amount of bromo-ester remaining after various time intervals. The determination was made by pouring the contents of each of a pair of bulbs, which had been heated for the same known time, into water (100 c.c.) to which 2N-aqueous sodium hydroxide (7 c.c.) had previously been added. This treatment produces a practically instantaneous hydrolysis of bromo-ester to bromo-acid without causing further detachment of the bromine atom. The two solutions were then extracted with ether in order to remove any methyl bromide, and the concentration of bromide ions in one of them was determined by titration with silver nitrate and ammonium thiocyanate. The other was treated with a further 7 c.c. of 2N-aqueous sodium hydroxide and boiled for 30 minutes, in order to hydrolyse all the bromopropionic acid to lactic acid; then the bromide ion present in this solution was determined. The difference between the two amounts of bromide ion represented the amount of bromo-ester which remained undecomposed when the two bulbs were removed from the thermostat. The method was checked by blank experiments and shown to be reliable.

The results are in Table VII. The concentrations of bromide ion are in c.c. of 0·1N-silver per 10 c.c. of solution. The mean first-order rate constant is 2·95 × 10^{-6} sec.$^{-1}$.

TABLE VII.

Time (hours).	Bromide ion (1).	Bromide ion (2).	Bromide ion (2) − (1).	10^6k_1 (sec.$^{-1}$).	Time (hours).	Bromide ion (1).	Bromide ion (2).	Bromide ion (2) − (1).	10^6k_1 (sec.$^{-1}$).
0·00	0·00	60·1	60·1	—	65·00	3·16	34·5	31·3	2·79
23·25	1·14	47·4	46·3	3·11	87·50	5·12	29·4	24·3	2·88
39·00	1·98	41·1	39·1	3·01					

Reaction of Methyl d-*α-Bromopropionate with Methyl Alcohol at* 100°.—(i) A solution of the ester (10 g.), having $\alpha_D^{23°}$ +29·0°, in methyl alcohol was made up to 100 c.c., and heated in sealed tubes at 100° for 25 hours. The methyl alcohol was removed by distillation, poured into 4 vols. of water, and extracted with ether. The residue from this extract was added to the main ester residue, and the whole was distilled at 20 mm. After several distillations the material was divided into a yellow head-fraction (0·7 g.), which proved to be impure methyl α-methoxypropionate containing residual methyl α-bromopropionate, and a main fraction (4·8 g.) consisting essentially of methyl α-bromopropionate. The crude methoxy-ester was lævorotatory: $\alpha_D^{23°}$ −0·67°. The bromo-ester was dextrorotatory, but much racemised: $\alpha_D^{22°}$ +1·00°.

(ii) A solution of the ester (20 g.), having $\alpha_D^{20°}$ +29·6°, in methyl alcohol was made up to 200 c.c., and heated in sealed tubes at 100° for 230 hours. When the tubes were opened, volatile products, presumably mainly methyl ether, boiled away, and the remaining solvent was then removed by distillation from a water-bath. The residue was taken up in ether, dried, and after removal of the solvent, distilled. The main fraction, b. p. 80°/5 mm., had $\alpha_D^{21°}$ −2·60°, but after several distillations the rotation rose to $\alpha_D^{20°}$ −2·72°, and then remained constant when in the final distillation a central cut was made. Analysis showed this product to consist of α-methoxypropionic acid containing 7% of residual α-bromopropionic acid (Found: C, 44·3; H, 7·3; Br, 3·77. Calc. for a mixture of 92·95% by weight of α-methoxypropionic acid and 7·05% of α-bromopropionic acid: C, 44·5; H, 7·4; Br, 3·77%).

Racemisation of Methyl d-*α-Bromopropionate in Methyl-alcoholic Solution at* 100°.—A solution of the bromo-ester (25 g.), having $\alpha_D^{20°}$ +29·6°, in methyl alcohol was made up to 250 c.c. Portions of this solution were enclosed in glass bulbs, and heated at 100° for various known times. The rotations of the contents of the bulbs were then measured at 20°. The results given in Table VIII are plotted in Fig. 2 (p. 1215). It is shown in the introduction that nearly the whole of the fall of rotatory power is due to racemisation of the bromo-ester by two mechanisms operating simultaneously.

TABLE VIII.

Time (hrs.)	0·00	1·70	2·30	3·63	4·23	5·25	7·00	9·25	13·00	14·50
$\alpha_D^{20°}$	+1·86°	+1·55°	+1·42°	+1·20°	+1·02°	+0·82°	+0·56°	+0·25°	+0·02	−0·01

Rate of Reaction between Sodium Methoxide and Sodium dl-*α-Bromopropionate in Methyl Alcohol at* 64·0°.—The methyl alcohol was dried by means of magnesium, and the α-bromopropionic acid was dried over phosphoric oxide in a vacuum. The following is a representative selection from our experiments (cf. Table IX, in which second-order rate constants, k_2, are in min.$^{-1}$ g.-mol.$^{-1}$ l. and first-order constants, k_1, in min.$^{-1}$).

(i) The acid (9·83 g.) was added to 1·69*N*-methyl-alcoholic sodium methoxide (190 c.c.), and the solution was made up to 250 c.c. at room temperature, and enclosed in 10 c.c. portions in sealed bulbs. In order to obtain the initial concentration (a) of sodium methoxide, a bulb was shaken for 1 minute in the thermostat at 64°, and its contents then titrated with 0·4899*N*-sulphuric acid: required 19·95, 20·00 c.c., and hence $a = 0·9197$. The other bulbs were used to estimate the concentration of bromide ions formed after different times at 64·0°; the estimation was performed by titration with silver nitrate and ammonium thiocyanate. The initial concentration of sodium α-bromopropionate (b) was given by the final, less the initial, concentration of bromide; $b = 0·2007$. All concentrations are corrected for thermal expansion, the factor used being 0·94. Rate constants are in min.$^{-1}$ g.-mol.$^{-1}$ l.

(ii) A solution of the acid (9·640 g.) in 1·078*N*-methyl-alcoholic sodium methoxide (175 c.c.) was made up to 250 c.c. with dry methyl alcohol. The initial concentrations were $a = 0·4650$ and $b = 0·2192$. The estimations were performed as in expt. (i). The final concentration of sodium methoxide should be $a - b = 0·2458$. A direct determination by titration (10 c.c.) with 0·4899*N*-sulphuric acid (required 5·55 c.c.) gave the value 0·2464*N*. The concentrations are corrected for expansion.

(iii) The acid (9·9470 g.) was added to a methyl-alcoholic solution (229 c.c.) which was 0·852*N* with respect to sodium methoxide, and contained 15·9 g. of sodium bromide per 270 c.c. The initial concentrations, measured as usual after shaking the bulbs for 1 minute in the thermostat, were $a = 0·4604$, $b = 0·2281$, $[NaBr]_{initial} = 0·5038$. The concentrations are corrected.

(iv) The acid (1·2042 g.) and 0·2*N*-methyl-alcoholic sodium methoxide (79 c.c.) were together made up to 250 c.c. with dry methyl alcohol. The initial concentrations, determined as usual, were $a = 0·0300$, $b = 0·0309$. The reaction was followed by determination of both bromide ions and alkalinity. The concentrations in Table IX are expressed in c.c. of 0·02500*N*-bromide, or 0·0268*N*-alkali per 10 c.c. of solution. All concentrations in this experiment are uncorrected

for thermal expansion, since the rate constants are now dimensionless with respect to concentration.

(v) A solution of the acid (1·2014 g.) in 0·2*N*-methyl-alcoholic sodium methoxide (118 c.c.) was made up to 250 c.c. with anhydrous methyl alcohol. The initial concentrations were $a = 0{\cdot}0577$ and $b = 0{\cdot}0309$. The reaction was followed by determination of both bromide ions and alkalinity. In Table IX, $a - x$ is expressed in c.c. of 0·0268*N*-alkali, and $b - x$ in c.c. of 0·02500*N*-bromide, per 10 c.c. of solution. Concentrations are uncorrected for expansion.

TABLE IX.

Expt. (i).

t (min.).	[Br^-].	$a - x$.	$b - x$.	10^2k_2.
0·0	0·0404	—	—	—
1·5	0·0541	0·9060	0·1870	5·16
4·0	0·0747	0·8854	0·1664	5·19
7·0	0·0974	0·8627	0·1437	5·35
10·0	0·1143	0·8458	0·1268	5·22
14·0	0·1362	0·8239	0·1049	5·09
20·0	0·1591	0·8010	0·0820	5·25
29·0	0·1845	0·7756	0·0566	5·25
45·0	0·2071	0·7530	0·0340	4·87
62·0	0·2236	0·7365	0·0175	4·97
77·0	0·2316	0·7285	0·0095	5·09
"∞"	0·2411	0·7190	—	—

Expt. (ii).

t (min.).	[Br^-].	$a - x$.	$b - x$.	10^2k_2.
0	0·0160	—	—	—
5	0·0307	0·4503	0·2045	3·02
10	0·0460	0·4350	0·1892	3·26
15	0·0608	0·4202	0·1744	3·45
20	0·0698	0·4112	0·1654	3·22
30	0·0888	0·3922	0·1464	3·16
45	0·1114	0·3696	0·1238	3·09
65	0·1355	0·3455	0·0997	3·07
90	0·1575	0·3235	0·0777	3·05
120	0·1792	0·3018	0·0560	3·16
150	0·1924	0·2886	0·0428	3·14
190	0·2051	0·2759	0·0301	3·13
230	0·2135	0·2675	0·0217	3·09
280	0·2208	0·2602	0·0144	3·09
"∞"	0·2352	0·2458	—	—

Expt. (iii).

t (min.).	[Br^-].	$a - x$.	$b - x$.	10^2k_2.
0	0·5038	—	—	—
10	0·5522	0·4120	0·1797	5·47
16	0·5719	0·3923	0·1600	5·23
23	0·5898	0·3744	0·1421	4·99
31	0·6104	0·3538	0·1215	5·08
40	0·6243	0·3399	0·1076	4·82
50	0·6421	0·3221	0·0898	4·95
63	0·6553	0·3089	0·0766	4·73
79	0·6696	0·2946	0·0623	4·64
96	0·6826	0·2816	0·0493	4·67
121	0·6953	0·2689	0·0366	4·60
146	0·7076	0·2566	0·0243	4·88
176	0·7129	0·2513	0·0190	4·60
211	0·7213	0·2429	0·0106	4·96
"∞"	0·7319	0·2323	—	—

Expt. (iv).

t (min.).	$b - x$.	10^3k_1.	$a - x$.	10^3k_1.
0	12·35	—	11·18	—
30	11·12	3·50	10·18	3·13
70	9·65	3·53	8·63	3·70
118	8·38	3·29	7·08	3·87
170	7·17	3·20	6·13	3·53
230	5·90	3·21	4·48	3·98
310	4·64	3·16	3·53	3·72
430	3·17	3·16	2·43	3·55
600	2·12	2·94	—	—

Expt. (v).

t (min.).	$b - x$.	10^2k_1.	$a - x$.	10^3k_1.
0	12·35	—	21·52	—
30	10·96	3·98	19·90	4·61
65	9·83	3·51	19·00	3·45
110	8·33	3·58	17·30	3·73
165	6·86	3·56	16·40	3·18
235	5·50	3·44	14·55	3·45
310	4·31	3·40	13·45	3·33
430	2·92	3·35	11·40	3·83
600	1·77	3·24	—	—

Expt. (vi).

t (min.).	[Br^-].	$b - x$.	10^3k_1.
0	0·13	12·31	—
42	1·85	10·59	3·59
64	2·71	9·73	3·67
85	3·37	9·07	3·59
112	4·06	8·38	3·43
140	4·94	7·50	3·53
150	5·11	7·33	3·46
173	5·55	6·89	3·36
204	6·36	6·08	3·46
245	7·01	5·43	3·34
295	7·85	4·59	3·34
356	8·63	3·81	3·30
420	9·27	3·17	3·23
505	9·98	2·46	3·19
"∞"	12·44	—	—

Expt. (vii).

	α.		β.	
t (min.).	$a - x$.	10^3k_1.	$a - x$.	10^3k_1.
0	11·50	—	11·44	—
30	—	—	10·57	2·64
30·5	10·15	4·01	—	—
50	9·90	3·00	10·15	2·40
75	9·37	2·73	9·63	2·24
05	8·10	3·34	9·15	2·13

	α.		β.	
t (min.).	$a - x$.	10^3k_1.	$a - x$.	10^3k_1.
145	6·90	3·52	8·35	2·17
198	5·72	3·53	7·15	2·37
240	4·90	3·55	6·85	2·14
295	4·00	3·58	5·55	2·45
363	3·30	3·44	5·00	2·28
490	2·30	3·29	4·25	2·02

(vi) A solution of the acid (2·4030 g.) in 0·3992*N*-sodium methoxide (79 c.c.) was made up to 250 c.c. The initial concentrations were $a = 0{\cdot}0584$, $b = 0{\cdot}0616$. The concentrations are uncorrected, and, in Table IX, are in c.c. of 0·0500*N*-bromide ion per 10 c.c. of solution.

(vii) A solution, containing the acid (2·4034 g.) and 0·1N-sodium methoxide (330 c.c.), and made up to 500 c.c., was divided into two equal portions. The first (α) was studied in the usual way, and the second (β) after additions of 12·9 g. of sodium bromide. The initial concentrations were for (α) a = 0·0309 and for (β) a = 0·0306 and $[NaBr]_{initial}$ = ca. 0·50N. The concentrations are uncorrected, and, in Table IX, are in c.c. of 0·0268N-alkali per 10 c.c. of solution.

Action of Concentrated (N) *Sodium Methoxide on Sodium* d-*α-Bromopropionate in Methyl Alcohol at* 64°.—A solution of the acid (9·65 g.), $\alpha_D^{20°}$ +12·9°, in 1·39N-methyl-alcoholic sodium methoxide (226 c.c.) was made up to 250 c.c. with dry methyl alcohol, heated at 64° for 18·5 hours, neutralised with methyl-alcoholic sulphuric acid and evaporated on the steam-bath. Water (75 c.c.) was then added, and the whole evaporated to 35 c.c., acidified with 18 c.c. of dilute sulphuric acid (50% by vol.), and extracted many times with ether. The methoxy-acid (4·9 g.), b. p. 103—104°/22 mm., had $\alpha_D^{26°}$ (l = 2·5 cm.) −4·95° (Found: C, 45·7; H, 7·9. Calc.: C, 46·1; H, 7·7%).

Action of Dilute (N/16) *Sodium Methoxide on Sodium* d-*α-Bromopropionate in Methyl Alcohol at* 64°.—A solution of the bromo-acid (9·696 g.), $\alpha_D^{20°}$ +12·9°, in 0·1725N-methyl-alcoholic sodium methoxide (810 c.c.) was made up to 1000 c.c. with dry methyl alcohol, heated at 64° for 26 hours, neutralised with methyl-alcoholic hydrogen chloride, and evaporated to dryness. The residue was dissolved in 15 c.c. of 6N-aqueous sulphuric acid, and extracted thoroughly with ether. The methoxy-acid (5·0 g.), b. p. 110°/30 mm., had $\alpha_D^{26°}$ (l = 2·5 cm.) +4·47° (Found: C, 45·5; H, 7·9%).

Rate of Reaction of α-Bromopropionic Acid in Aqueous Sulphuric Acid at 100°.—The acid (3·808 g.) was made up to 250 c.c. with 0·4899N-aqueous sulphuric acid, and portions of 10 c.c. were enclosed in bulbs which were heated in a boiling water-bath for known lengths of time before estimation of the bromide ion. The initial estimation was made 10 minutes after putting a bulb into the bath, and the reading was treated as corresponding to zero time. The values of $b - x$ in Table X are in c.c. of 0·0508N-bromide ion per 10 c.c. of solution. The constants are in min.$^{-1}$.

TABLE X.

t (min.).	$b - x$.	10^3k_1.	t (min.).	$b - x$.	10^3k_1.	t (min.).	$b - x$.	10^3k_1.
0	18·27	—	70	12·59	5·32	175	7·04	5·45
10·1	17·29	5·45	85	11·59	5·36	200	5·99	5·58
20	16·39	5·42	100	10·64	5·41	230	5·11	5·54
30	15·49	5·49	110	10·01	5·47	260	4·38	5·49
41	14·54	5·57	130	8·84	5·58	295	3·71	5·42
55	13·46	5·55	150	7·94	5·55			Mean 5·48

Reaction of d-*α-Bromopropionic Acid with Aqueous Sulphuric Acid.*—The acid (15·00 g.), $\alpha_D^{25°}$ +19·00°, was made up to 1000 c.c. with 0·534N-aqueous sulphuric acid, and the solution heated at 88—94° for 50 hours. The neutralised solution was evaporated under reduced pressure until a considerable amount of salt had separated, and then filtered, the salts being washed with absolute ethyl alcohol. The washings, combined with the filtrate, were evaporated to dryness, and the residue was further evaporated with additions of dry ethyl alcohol, and warmed under reduced pressure, in order to complete the removal of water. The dried residue was then heated under reflux for 3 hours with anhydrous ethyl alcohol (140 c.c.) and concentrated sulphuric acid (7 g.). The solution was neutralised with ethyl-alcoholic sodium ethoxide, and evaporated to remove alcohol, the crystalline salts being separated by filtration. The residue was distilled completely at 20 mm., and the ethyl lactate again distilled. It had b. p. 64°/22 mm. (4·5 g.), and $\alpha_D^{20°}$ −0·61° (Found: C, 50·4; H, 8·7. Calc.: C, 50·8; H, 8·5%).

Rate of Racemisation of d-*α-Bromopropionic Acid in Aqueous Sulphuric Acid.*—(i) A solution of the acid (7·612 g.), having $\alpha_D^{25°}$ +19·0°, in 0·535N-aqueous sulphuric acid was made up to 500 c.c. Portions of 40 c.c. were enclosed in glass bulbs, heated for known times at 100°, then chilled and examined for rotatory power. The observed rotations are in Table XI, in which they are compared with the rotations calculated from the theoretical equation (see Appendix).

(ii) Another experiment with the same acid (7·162 g.) was carried out in the same way (all other concentrations and quantities being unchanged) in order to investigate more carefully the earlier part of the reaction. The rotations are in the right-hand part of Table XI.

These results are plotted in Fig. 4. It was shown by special experiments that, within the range of concentration with which we are here concerned, the rotation of a solution of d-α-bromopropionic acid in 0·53N-aqueous sulphuric acid is accurately proportional to the concentration of the optically active acid. The rotatory power of lactic acid in the sulphuric acid medium

TABLE XI.

($\alpha_D^{22°}$ refers to l = 40 cm.)

(i).						(ii).			
t (min.).	$\alpha_D^{22°}$.	α (calc.).	t (min.).	$\alpha_D^{22°}$.	α (calc.).	t (min.).	$\alpha_D^{25°}$.	t (min.).	$\alpha_D^{25°}$.
1	+0·69°	+0·71°	137	+0·01°	+0·02°	5	+0·65°	55	+0·29°
31	+0·49	+0·47	181	±0·00	−0·01	15	+0·58	65	+0·21
51	+0·33	+0·32	226	±0·00	±0·00	25	+0·51	75	+0·16
81	+0·14	+0·15	266	±0·00	±0·00	35	+0·44	85	+0·11
106	+0·05	+0·06				45	+0·37	95	+0·09

was determined by making up a solution of recrystallised l-lactic acid (2·098 g.) in 0·535N-aqueous sulphuric acid to 250 c.c. and measuring the rotation: $\alpha_D^{20°}$ (l = 40 cm.) = +0·05°. From this figure we can deduce that the lactic acid formed in the experiments recorded in Table XI would not make an appreciable contribution to the rotations.

Effect of Hydrogen-ion Concentration on Rate of Reaction of α-Bromopropionic Acid in Aqueous Sulphuric Acid.—Two experiments with different initial concentrations of sulphuric acid were carried out simultaneously, a boiling water-bath being used as thermostat. This was done in order to eliminate any influence on the rate difference, arising from the effect of varying atmospheric pressure on the exact temperature of the bath. In expt. (i) a solution of α-bromopropionic acid (9·502 g.) in water was made up to 50 c.c., and 20 c.c. of this were made up to 250 c.c. with 0·5345N-aqueous sulphuric acid. The sulphuric acid concentration was therefore 0·491N, and that of the bromopropionic acid 0·0993M. Portions of 10 c.c. were sealed up in separate bulbs, and heated in the bath for the times indicated in Table XII. The values of $b - x$ are expressed in c.c. of 0·03948N-ammonium thiocyanate per 10 c.c. sample; and the rate constants k_1 are in min.$^{-1}$. An initial estimation made 10 minutes after putting the bulbs into the bath was treated as corresponding to zero time. In expt. (ii) a solution of α-bromopropionic acid (4·857 g.) in water was made up to 25 c.c., and 20 c.c. of this were diluted to 250 c.c. with 0·2672N-aqueous sulphuric acid. The sulphuric and α-bromopropionic acid concentrations were thus 0·245N and 0·1013M respectively. The reaction was followed in the manner described, with the results recorded in Table XII.

TABLE XII.

Expt. (i).			Expt. (ii).		
t (min.).	$b - x$.	10^3k_1 (min.$^{-1}$).	t (min.).	$b - x$.	10^3k_1 (min.$^{-1}$).
0·0	24·85	—	0·0	24·80	—
10·0	23·25	6·65	10·0	22·85	(8·17)
25·0	21·20	6·35	21·0	21·20	7·45
31·0	20·50	6·20	30·0	19·70	7·68
51·0	18·38	5·90	40·0	18·45	7·38
75·8	15·70	6·07	58·0	16·23	7·29
90·0	14·65	5·88	70·0	15·00	7·18
97·0	14·05	5·88	90·0	13·18	7·04
127·0	12·05	5·70	122·0	10·50	7·04
187·0	8·29	5·85	160·0	8·10	7·00
212·2	7·25	5·80	220·0	5·57	6·79
270·0	5·52	5·57	300·0	3·25	6·77
		Mean 5·99			Mean 7·18

Rate of Reaction between Sodium Hydroxide and Sodium α-Bromopropionate in Aqueous Solution at 64·0°.—Six experiments are here recorded, covering the range of concentration investigated. In Table XIII, second-order rate constants (k_2) are in min.$^{-1}$ g.-mol.$^{-1}$ l., and first-order constants (k_1) in min.$^{-1}$.

(i) α-Bromopropionic acid (9·8489 g.) and 1·971N-aqueous sodium hydroxide (164 c.c.) were made up to 250 c.c. at 64·0°, all materials being previously brought to this temperature. After 7 minutes in the thermostat, titrations were commenced, 10 c.c. being withdrawn for each estimation of bromide ion. The concentration of sodium hydroxide at the starting time (a) was measured by titration with sulphuric acid; the corresponding concentration of sodium α-bromopropionate (b) is taken as the difference between the initial and the " infinity " value of bromide ion.

(ii) α-Bromopropionic acid (9·8405 g.), water (142 c.c.) and 1·971N-aqueous sodium hydroxide (98 c.c.) were together made up to 250 c.c. at 64·0°, the method being otherwise as under (i).

(iii) A solution of the acid (1·2042 g.) in water (180 c.c.) was mixed with 0·2597N-aqueous sodium hydroxide (67 c.c.) and made up to 250 c.c. at 64·0°. The withdrawal of samples for

estimation of bromide ion was commenced 5 minutes later. The concentrations of free sodium hydroxide at zero and " infinite " time, estimated by titration with sulphuric acid, were 0·0348N and 0·0056N respectively. The corresponding concentrations of bromide ion were 0·0014N and 0·0310N respectively. In Table XIII, the values of $b - x$ are expressed in c.c. of thiocyanate equivalent to 10 c.c. of the solution; the value of b, given as 18·41 c.c., corresponds to 0·0310 − 0·0014 = 0·0296N.

(iv) A solution of the acid (1·2042 g.) in 0·2597N-aqueous sodium hydroxide (100 c.c.) was made up to 250 c.c. at 64°. The estimations were performed as under (iii) except that the titrations with sulphuric acid were omitted.

TABLE XIII.

Expt. (i).

t (min.).	[Br⁻].	$a - x$.	$b - x$.	10^2k_2.
0·00	0·0757	0·9552	0·1799	—
1·65	0·0867	0·9442	0·1689	4·05
2·27	0·0903	0·9406	0·1653	3·94
3·27	0·0953	0·9356	0·1603	3·74
4·50	0·1030	0·9279	0·1526	3·90
6·17	0·1108	0·9201	0·1448	3·75
8·25	0·1215	0·9094	0·1341	3·83
10·40	0·1312	0·8997	0·1244	3·84
12·95	0·1403	0·8906	0·1153	3·74
15·7	0·1515	0·8794	0·1041	3·82
19·5	0·1638	0·8671	0·0918	3·81
24·6	0·1782	0·8527	0·0774	3·83
31·9	0·1942	0·8367	0·0614	3·81
43·6	0·2130	0·8179	0·0426	3·80
55·2	0·2260	0·8049	0·0296	3·82
69·3	0·2371	0·7938	0·0185	3·89
92·4	0·2460	0·7849	0·0096	3·80
" ∞ "	0·2556	0·7753	—	—

Expt. (ii).

t (min.).	[Br⁻].	$a - x$.	$b - x$.	10^2k_2.
0·00	0·0378	0·4650	0·2239	—
8·75	0·0706	0·4322	0·1911	4·04
15·27	0·0906	0·4122	0·1711	4·11
21·30	0·1066	0·3962	0·1551	4·03
26·25	0·1175	0·3853	0·1442	3·98
33·75	0·1338	0·3690	0·1279	4·04
46·1	0·1542	0·3486	0·1075	4·01
61·0	0·1748	0·3290	0·0869	4·08
80·3	0·1929	0·3099	0·0688	4·00
96·0	0·2115	0·2913	0·0502	4·43
141·3	0·2282	0·2746	0·0335	4·03
187·0	0·2429	0·2599	0·0188	4·21
" ∞ "	0·2617	0·2411	—	—

Expt. (iii).

t (min.).	[Br⁻].	$b - x$.	10^3k_1.
0·0	0·56	11·84	—
12·0	1·43	10·97	6·37
20·7	2·15	10·25	6·98
30·6	2·90	9·50	7·20
40·8	3·60	8·80	7·28
51·2	4·22	8·18	7·22
62·3	4·80	7·60	7·12
78·3	5·60	6·80	7·09
132·5	7·75	4·65	7·06
152·5	8·32	4·08	6·99
171·5	8·80	3·60	6·94
208·5	9·45	2·95	6·68
253·0	10·33	2·07	6·90
" ∞ "	12·40	—	—

Expt. (iv).

t (min.).	[Br⁻].	$b - x$.	10^3k_1.
0·0	0·63	12·21	—
12·6	1·67	11·17	7·07
21·7	2·32	10·52	6·87
30·6	3·00	9·84	7·05
41·0	3·70	9·14	7·06
50·4	4·42	8·42	7·37
62·1	5·02	7·82	7·18
75·3	5·76	7·08	7·24
89·1	6·39	6·45	7·16
106·3	7·10	5·74	7·10
180·0	9·37	3·47	6·99
210·0	9·86	2·98	6·72
266·0	10·72	2·12	6·58
" ∞ "	12·84	—	—

Expt. (v).

t (min.).	[Br⁻].	$b - x$.	10^3k_1.
0·0	0·64	11·80	—
11·7	1·60	10·84	7·26
21·0	2·37	10·07	7·56
31·0	3·13	9·31	7·65
41·0	3·80	8·64	7·61
50·0	4·40	8·04	7·67
62·0	5·03	7·41	7·51
74·5	5·65	6·79	7·42
90·0	6·40	6·04	7·46
110·4	7·22	5·22	7·39
131·0	7·95	4·49	7·38
187·0	9·43	3·01	7·31
222·4	10·05	2·39	7·18
260·5	10·55	1·89	7·03
300·4	11·10	1·30	7·34
" ∞ "	12·44	—	—

Expt. (vi).

t (min.).	[Br⁻].	$b - x$.	10^3k_1.
0·0	1·27	18·41	—
10·8	2·95	16·73	8·85
20·0	4·27	15·41	8·89
29·0	5·40	14·28	8·75
40·0	6·68	13·00	8·70
49·0	7·57	12·11	8·55
61·0	8·65	11·03	8·40
77·0	10·10	9·58	8·48
96·0	11·37	8·31	8·29
142·0	13·75	5·93	7·98
171·0	14·85	4·73	7·95
206·0	15·97	3·71	7·78
246·0	16·90	2·78	7·69
299·0	17·70	1·98	7·46
360·0	18·35	1·33	7·30
" ∞ "	19·68	—	—

(v) The acid (2·4062 g.) and 0·259*N*-aqueous sodium hydroxide (133 c.c.) were together made up to 250 c.c. at 64°. The estimations were carried out as under (iii). The initial and the final concentration of sodium hydroxide, as determined by titration with sulphuric acid, were 0·0678*N* and 0·0095*N*, and those of bromide ion were 0·0032*N* and 0·0628*N*. In the table the value of *b*, given as 11·80 c.c., corresponds to 0·0596*N*.

(vi) The acid (3·832 g.) and 0·2597*N*-aqueous sodium hydroxide were together made up to 250 c.c. at 64°, and the estimations were performed as under (iii). The initial and the final concentration of sodium hydroxide as estimated by titration with acid were 0·1080*N* and 0·0161*N*; the corresponding concentrations of bromide ion were 0·00641*N* and 0·0995*N*. The value of *b*, given as 18·41 c.c., is thus 0·0931*N*.

Action of Concentrated (N) *Sodium Hydroxide on Sodium* d-α-*Bromopropionate in Water at* 64°.—The acid (15·01 g.), $\alpha_D^{18.5°}$ +19·12°, was added to water (133 c.c.) and 1·971*N*-aqueous sodium hydroxide (250 c.c.) at 64°. After 3 hours at this temperature, the mixture was neutralised with 6*N*-aqueous sulphuric acid, and evaporated to dryness under reduced pressure. The residue was re-evaporated with the addition of absolute ethyl alcohol, and heated in a vacuum for 10 minutes. It was then heated under reflux for 4 hours with dry ethyl alcohol (140 c.c.) and concentrated sulphuric acid (7 g.). The cooled product was filtered, and the salts washed with dry ethyl alcohol. The combined filtrate and washings were neutralised with ethyl-alcoholic sodium ethoxide and evaporated, the salts being removed from time to time by filtration, and, in the last stages, by precipitation with ether and filtration. The residue of ethyl lactate, after two distillations, had b. p. 66°/23 mm., $\alpha_D^{26°}$ −2·26° (Found: C, 50·7; H, 8·8. Calc.: C, 50·8; H, 8·5%).

Action of Dilute (M/16) *Sodium Hydroxide on Sodium* d-α-*Bromopropionate in Water at* 64°.—A solution of the acid (15·01 g.), $\alpha_D^{18.5°}$ +19·12°, in water (740 c.c.) was mixed with 0·2597*N*-aqueous sodium hydroxide (755 c.c.) and kept at 64° for 16·25 hours. It was then neutralised with 0·5*N*-aqueous sulphuric acid, and evaporated to dryness, and the residue dehydrated, and esterified with ethyl alcohol as described above. The ethyl lactate had b. p. 64°/21 mm., $\alpha_D^{26°}$ +3·12° (Found: C, 50·4; H, 8·7%).

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255. *Reaction Kinetics and the Walden Inversion. Part IV. Action of Silver Salts in Hydroxylic Solvents on β-*n*-Octyl Bromide and α-Phenylethyl Chloride.*

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Our investigation of the Walden inversion having thus far been confined to homogeneous mechanisms of substitution, we here set out to cover similar ground with respect to the important group of heterogeneous mechanisms which involve the use of silver salts. This paper deals with the hydroxylation and ethoxylation of halides containing hydrogen and alkyl groups only, or hydrogen, alkyl and aryl groups, at the seat of substitution, the examples being β-*n*-octyl bromide and α-phenylethyl chloride.

In the controlling kinetic investigation it is proved that the reaction with silver oxide is catalysed by silver bromide, and that, at equivalent concentrations and similar conditions of catalysis by silver halide, silver nitrate and silver acetate act at the same rate. In all cases the reagent is adsorbed silver ions: with soluble salts the only surface catalyst is the silver halide, but with silver oxide the reaction goes both on the silver halide and on the silver oxide: the primary function of silver oxide is to maintain a supply of silver ions, but it also provides an active surface.

The optical investigation deals with the hydroxylation and ethoxylation of β-*n*-octyl bromide by means of silver oxide, nitrate and acetate, and the hydroxylation of α-phenylethyl chloride by means of silver oxide. All the products of substitution have a predominantly inverted configuration, but all are more or less considerably racemised, especially that from the aralphyl halide. The amount of racemisation is increased when the hydroxylic solvent is diluted with a non-hydroxylic solvent. Quantitative particulars are given.

In the following experiments we endeavour to establish the space-orientation of the hydroxylation or alkoxylation of alkyl halides by means of silver salts in aqueous or alcoholic media. We have used two alkyl halides, one of which, β-*n*-octyl bromide, is typically aliphatic, whilst the other, α-phenylethyl chloride, may be taken to represent the series of aralphyl halides. The problem of halogeno-acids and their derivatives is considered separately in Part V. As silver salts, we have used *silver oxide in suspension*, and the nitrate and acetate in solution.

The work divides itself as usual into the study of the kinetics of substitution and the examination of the optical effect, and we shall consider first the evidence of mechanism given by the kinetic observations.

A number of experiments have been made on the hydrolysis of β-*n*-octyl bromide with a suspension of silver oxide in "63%" aqueous ethyl alcohol at the boiling point. At this temperature the displacement of bromine from the alkyl bromide in the absence of an added reagent becomes substantially complete only after several days; whereas in the presence of a moderate excess of silver oxide the reaction is completed in a few hours. Hence we can assume that the reaction which takes place in the presence of silver oxide depends in an essential way on this reagent, although homogeneous interaction with the solvent must also occur to a small extent.

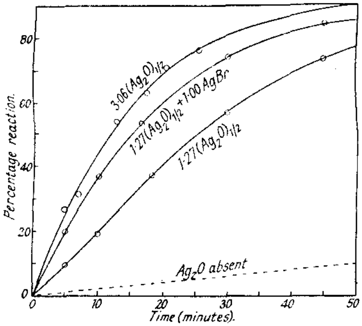
The product of the reaction with silver oxide is not simply β-*n*-octyl alcohol, but a mixture of this and ethyl β-*n*-octyl ether; in fact, the two substances which would be formed by interaction of the bromide with the solvent alone, in the absence of any silver oxide. Unless we assume that the silver ethoxide can exist in the presence of a large amount of water, it is necessary to conclude that the ethoxyl, and likewise the hydroxyl, groups in the reaction products come directly from alcohol and water molecules of the *solvent, not from silver compounds. Thus the suggestion arises that the essential* function of the silver oxide is to supply silver ions.

Further evidence of mechanism arises from our observation that the reaction is autocatalytic with respect to silver bromide, and can be considerably accelerated by the prior addition of this substance. The reaction obviously occurs on the surface of the silver bromide; and since we cannot suppose that so rapid a process involves the interaction of two solids, the adsorbed reagents must be the soluble alkyl halide and some dissolved ion derived from the silver oxide—evidently the silver ion.

Although heterogeneous catalysis by silver bromide in the hydrolysis of alkyl halides has not previously been observed for the reaction with silver oxide, it is well known for the reaction with soluble silver salts, such as silver nitrate. Reactions with soluble silver salts were at first thought to be homogeneous and bimolecular (Chiminello, *Gazzetta*, 1895, **25**, [ii], 410; v. Biron, *J. Russ. Phys. Chem. Soc.*, 1900, **30**, 667), but more comprehensive investigations revealed relations which were not consistent with any simple form of kinetics (Burke and Donnan, J., 1904, **85**, 555; *Z. physikal. Chem.*, 1909, **69**, 148; Donnan and Potts, J., 1910, 1882; Pierce and Weigle, *Amer. Chem. J.*, 1912, **48**, 243). The heterogeneous catalysis by silver bromide was discovered by Senter for methyl iodide (J., 1910, **97**, 346), and was confirmed by Baker for benzyl bromide (J., 1934, 987). Further confirmation has arisen in the study of halogeno-acids. In all these cases in which soluble silver salts are employed, the reagent must be *silver ions; and hence it* would appear that heterogeneous catalysis by silver halides is diagnostic of the reaction of silver ions with alkyl halides.

There is one respect in which the behaviour of silver oxide is more complicated than that of soluble silver salts, as our results with β-*n*-octyl bromide show. Although the reaction of this substance with silver oxide in aqueous alcohol is demonstrably autocatalytic with respect to silver bromide, it commences, in the absence of any initially added silver bromide, with a finite velocity, which is much too great to represent merely the homogeneous interaction with the solvent. Moreover, the reaction–time curve shows no marked point of inflexion, and usually appears to be concave to the time-axis right from the origin. The rate throughout a run increases, furthermore, with the amount of silver oxide employed, although we may presume that the volume-concentration of silver ions in solution, and therefore their surface-density in any given surface, being determined

by a solubility, would be independent of the quantity of suspended silver oxide. These points are illustrated by the reaction–time curves of the figure. The facts are all explained if we suppose that silver oxide, as well as silver halides, can provide an active surface: in hydrolysis by silver oxide, unlike hydrolysis with fully dissolved silver salts, a suitable surface is available from the commencement of reaction, and the greater this surface the greater the speed of reaction. A curious result of this catalysis is that the decrease of speed due to the destruction of silver oxide in the course of a run is often more or less off-set by the increase due to the formation of silver bromide: with suitably chosen initial quantities and concentrations the two effects can be made to balance sufficiently well to enable the reaction to be expressed by means of a first-order rate equation; the constant of which, however, has no definite chemical meaning. Many such accidental compensations occur in the literature of hydrolysis with silver salts.



Our kinetic observations on the hydrolytic action of silver oxide thus lead us to the view that this reagent has two functions: first, it maintains a supply of silver ions in the solution: and secondly, it provides a surface on which the attack of these ions on the alkyl halide can proceed. The precipitated silver halide furnishes a second surface also suitable for this purpose.

Since the concentration of dissolved silver ions which can be maintained by suspended silver oxide is inevitably small, our interpretation requires that, in the initial presence of suitable amounts of silver bromide, hydrolysis with moderately concentrated solutions of soluble silver salts, such as silver nitrate, should proceed very much more rapidly than hydrolysis with suspensions of silver oxide. We have verified this by qualitative observations on a number of alkyl halides, and a more quantitative illustration is provided by observations on the hydrolysis of β-*n*-octyl bromide, initially in *M*/35-concentration in "63%" aqueous ethyl alcohol at 35°. When 1·25 mols. of dissolved silver nitrate were used as the hydrolysing agent (concentration *M*/28), without the initial addition of silver bromide, the time of half-change was 85 minutes; whilst with 1·00 mol. silver bromide in addition, it was 67 minutes; on the other hand, with 1·25 mols. of suspended silver oxide as hydrolysing agent the time of half-change was about 650 minutes. It should be mentioned that the solubility of silver oxide in the hydrolysis solutions is distinctly greater than in the pure solvent; thus a particular solution, filtered at about 35° after the completion of hydrolysis, was found to be *N*/780 with respect to silver ions.

In further support of the theory that the reagent is the adsorbed silver ion, we have made a comparison between silver nitrate and silver acetate with respect to the rates at

which they effect the hydrolysis of β-*n*-octyl bromide at similar concentrations. It seemed the more desirable to do this inasmuch as the peculiar kinetics obtaining in hydrolyses with silver nitrate have been repeatedly interpreted by assuming attack by undissociated silver nitrate molecules—a convenient theory since nobody claims to know the concentration of these molecules. A pair of experiments were carried out in which β-*n*-octyl bromide in *M*/100-solution in "63%" aqueous ethyl alcohol at 85° was hydrolysed on the one hand by means of 1·15 mols. of dissolved silver nitrate, and, on the other, by a similar amount of dissolved silver acetate. The two rate curves were coincident up to 40% of reaction, after which the experiment with the nitrate proceeded slightly faster than the other, probably on account of a difference in the condition or specific area of the silver halide surface in the two cases.

Heterogeneous catalysis by silver bromide in the hydrolysis of alkyl halides by means of soluble silver salts is confirmed by our experiments with β-*n*-octyl bromide. In all runs in which silver nitrate was employed without an initial addition of silver bromide, the reaction commenced with a period of acceleration, followed by an inflexion point and a deceleration. The initial addition of silver bromide removed the induction period, and accelerated the reaction, especially in the early stages.

Our general conclusion is that the hydrolysis of alkyl halides, either by means of sparingly soluble silver compounds such as the oxide, or of soluble silver salts such as the nitrate, consists essentially in the heterogeneous attack by silver ions on the alkyl halide at the surface of the silver halide, and also at the surface of silver oxide, if any is present. The available evidence does not, however, exclude the possibility that in the presence of considerable concentrations of silver ion some part of the attack may be homogeneous. It may be noted that the rôle ascribed to the silver halides is in general conformity with the large amount of available evidence concerning the tendency of those aliphatic halides which are not easily hydrolysed to combine with silver salts; and with the ability of soluble (ionised) silver salts to combine with silver halides: the adsorption equilibrium of silver ions on silver bromide has been studied by Fajans and Frankenburger (*Z. physikal. Chem.*, 1923, **105**, 255).

We now turn to the optical side of the research, and recall, first, that when β-*n*-octyl bromide, β-*n*-octyl alcohol and ethyl β-*n*-octyl ether have rotations of the same sign they have corresponding configurations (Part I); and also that a like statement is true for α-phenylethyl chloride, α-phenylethyl alcohol, and α-phenylethyl ethyl ether (Part II); so that in the case of either of these halides we can deduce the spatial orientation of hydroxylation or ethoxylation from the observed effect on the sign of rotation.

As far as we are aware, the previous literature contains only two records of the hydrolysis of optically active alkyl halides by means of silver salts; and one relates to β-*n*-octyl bromide, the other to α-phenylethyl chloride. Pickard and Kenyon state that, using moist silver oxide, they converted β-*n*-octyl bromide having $[\alpha]_D^{20°} \pm 27{\cdot}5°$ into optically pure β-*n*-octyl alcohol with $[\alpha]_D^{20°} \pm 9{\cdot}9°$ (*Ber.*, 1912, **45**, 1592); there must, however, be some inaccuracy here, because the rotation of the optically pure bromide is at least $[\alpha]_D^{20°} \pm 32{\cdot}5°$, and is probably close to $[\alpha]_D^{20°} \pm 33{\cdot}8°$, so the material used could not have given optically pure alcohol. We can suggest a possible cause of this discrepancy inasmuch as the authors' description is not specific with regard to the solvent used, and does not include any record of an analysis of the alcohol: if the solvent were aqueous ethyl alcohol, the isolated β-*n*-octyl alcohol would contain ethyl β-*n*-octyl ether, which is not easily removed by distillation, and has a considerably higher specific rotation than the β-*n*-octyl alcohol. McKenzie and Clough shook α-phenylethyl chloride with silver oxide and water at room temperature, and obtained a much racemised alcohol with an inverted sign of rotation (J., **1913**, **103**, 687). These authors did not, however, show to what extent the reaction under these conditions is independent of the hydrolysis which readily takes place in the presence of water alone: a demonstration on this point is necessary, because we know that the addition of, *e.g.*, potassium hydroxide to a mixture of α-phenylethyl chloride and water makes no difference to the hydrolysis, either kinetically or stereochemically (Part II). However, we have found that the hydrolysis under McKenzie and Clough's conditions takes place very much more rapidly than if the

silver oxide is omitted, so the optical results which they obtained must relate essentially to the reaction involving silver oxide.

In our further experiments we have employed solvents which completely dissolve the alkyl halides. β-*n*-Octyl bromide has been hydrolysed and alcoholysed in 60—63% aqueous ethyl alcohol under the following conditions: (1) With excess of silver oxide at the b. p. of the suspension. The products were β-*n*-octyl alcohol and ethyl β-*n*-octyl ether, formed in comparable amounts, and a little octylene. (2) With a small excess of silver nitrate in an initial concentration of approximately $M/20$ at 35°. The products were the alcohol and ether as before, together with small amounts of β-*n*-octyl nitrate and octylene. Qualitative examination of the stability of the nitrate towards hydrolysis indicated the improbability that any appreciable amount of alcohol or ether could have been formed by way of the nitrate; and this point is of importance in the interpretation of the optical results of substitution, since, if any appreciable amount of alcohol or ether were formed through a directly produced nitrate, we should have to consider the steric orientation of the decompositions of this substance. (3) With a small excess of silver acetate in an initial concentration of about $M/80$ at 80°. The products were β-*n*-octyl alcohol, ethyl β-*n*-octyl ether, and very small amounts of the octyl acetate and octylene. In this case it is unnecessary to consider whether or not any of the alcohol or ether arises by hydrolysis or alcoholysis of first-formed β-*n*-octyl acetate, because we know that the hydrolysis of a carboxylic ester does not involve an exchange of any bond of the alcoholic residue, and, therefore, that the configuration of any β-*n*-octyl alcohol or ether produced by way of the acetate would indicate the steric orientation of the nucleophilic substitution, just as well as alcohol and ether which are formed directly. (4, 5) α-Phenylethyl chloride has been hydrolysed in 60% and in 80% aqueous acetone by means of excess of silver oxide at the b. p.'s of the respective suspensions. The sole product in these experiments was α-phenylethyl alcohol.

Results and Conclusions.

The results are given in Table I, in which we have included the data obtained by McKenzie and Clough. The headings of the first six cols. of the table are self-explanatory. Col. 7 records the rotatory powers of the alkyl halides used, and col. 8 those of the alcohols, alkyl ethyl ethers or alkyl esters produced. Col. 9 shows the rotations of these substances, calculated to correspond to the best values we are able to assign to the rotatory powers of the optically pure halides: for β-*n*-octyl bromide we take the value $[\alpha]_D^{20°}$ 33·8°, or $\alpha_D^{20°}$ (l = 10 cm.*) 36·9°; and for α-phenylethyl chloride, the value $\alpha_D^{20°}$ 53·8°. In col. 10 these rotatory powers of the products of substitution are, where possible, expressed as percentages of the rotations of optically pure products: we assume the following values of $\alpha_D^{20°}$, *viz.*, β-*n*-octyl alcohol 8·1°, ethyl β-*n*-octyl ether 13·4°, α-phenylethyl alcohol 44·0°. In the last col. we give for comparison the similarly calculated percentage optical purity of the products formed by homogeneous unimolecular hydrolysis or alcoholysis (S_N1; cf. Part I and II) under conditions approximately corresponding as to solvent and temperature with those of the silver salt experiments.

The figures given in the penultimate column for the percentage retention of optical purity permit the following statements. In all cases the products of substitution show an inverted sign of rotation, and this, as we have seen, means an inverted configuration; all products, however, are more or less considerably racemised; the aralphyl halide undergoes substitution with particularly extensive racemisation; and in the hydrolysis of this halide racemisation increases markedly on diluting the reagent water with the inert solvent acetone.

Comparison of the last two columns indicates a close qualitative parallelism between the optical results obtained in the reactions with silver salts and those recorded in Parts I and II for substitution by the homogeneous unimolecular mechanism. Thus all the statements of the preceding paragraph would apply equally well to the data of the last column, even though the individual figures differ rather considerably from those of the penultimate column. The main general difference is that in the heterogeneous reactions

* All subsequent values of α_D refer to l = 10 cm. unless otherwise specified.

Table I.

Optical Effects of Reactions between Alkyl Halides and Silver Salts.

Alkyl halide.	Re-agent.	Equivs. Ag.	Solvent.	Approx. temp.	En-trant group.	Halide $\alpha_D^{20^\circ}$.	Alcohol, etc., $\alpha_D^{20^\circ}$. Obs.	Alcohol, etc., $\alpha_D^{20^\circ}$. Corr. stand. halide.	Opt. purity, %.	Do. for S_N1, %.
$C_8H_{17}Br$	Ag_2O	3·32	60% aq.-EtOH	80°	OH	−26·8°	+ 4·40°	+ 6·05°	−74·5	−66
,,	,,	3·32	60% aq.-EtOH	80	OEt	−26·8	+ 9·22	+12·7	−94·0	−74
,,	$AgNO_3$	1·21	63% aq.-EtOH	35	OH	−34·5	+ 5·68	+ 6·07	−74·8	—
,,	,,	1·21	63% aq.-EtOH	35	OEt	−34·5	+11·70	+12·5	−93·0	—
,,	,,	1·21	63% aq.-EtOH	35	ONO_2	−34·5	+11·36	+12·1	—	—
,,	AgOAc	1·00	63% aq.-EtOH	35—80	OH	−11·6	+ 1·78	+ 5·65	−70·0	—
,,	,,	1·00	63% aq.-EtOH	35—80	OEt	−11·6	+ 4·00	+12·7	−94·0	—
CHPhMeCl	Ag_2O	1·20	H_2O	20	OH	−32·0	+ 7·4	+12·4	−29·0*	−17
,,	,,	1·54	H_2O	20	,,	+53·7	−13·2	−13·2		
,,	,,	1·20	60% aq.-Me_2CO	70	,,	−47·2	+ 4·16	− 4·7	−10·7	− 5
,,	,,	1·20	80% aq.-Me_2CO	70	,,	−34·0	+ 0·80	− 1·3	− 3·0	− 2

* Experiments by McKenzie and Clough, *loc. cit.*

with silver salts the retention of optical purity is greater than in the homogeneous unimolecular reactions. These comparisons are discussed in Part VI.

Experimental.

Rate of Reaction between β-n-Octyl Bromide and Silver Oxide in 63% Aqueous Alcohol.—(i) The "63%" aqueous alcohol was prepared by mixing 13 vols. of purified anhydrous ethyl alcohol and 8 vols. of water. Three parallel experiments were performed each with a 0·14*M*-solution of the bromide in the solvent at its b. p. In the first experiment (*a*) 1·27 equivs. of silver oxide were added, in the second (*b*) 3·06 equivs., and in the third (*c*) 1·27 equivs. of silver oxide plus 1·00 equiv. of silver bromide. Samples (10 c.c.) were removed at various times from the boiling suspensions (by using a temporary increase of pressure over the surface of the liquid in order to fill the pipette), and run into an excess of concentrated chloride-free alcoholic potassium hydroxide (30 c.c.). This solution was filtered, and the precipitate was washed with anhydrous alcohol; the combined filtrate and washings were then hydrolysed completely by boiling for 2 hours under reflux. The liberated chloride ion was then estimated by the addition of silver nitrate, and back-titration with ammonium thiocyanate, ferric sulphate being used as indicator. The results are in Table II.

(ii) Two parallel experiments were carried out each with a 0·0285*M*-solution of the bromide in the same solvent at 35°. In one (*d*) 1·25 equivs. of silver oxide were added, and in the other (*e*) 5·00 equivs. The suspensions were stirred continuously, and samples were analysed as described above with results which are given in Table II.

In sets of parallel experiments silver oxide from the same batch was used. It was prepared with a small excess of silver nitrate, since the alternative of a small excess of alkali hydroxide involved some risk that adsorbed hydroxide ion would modify the solubility of the precipitate with respect to silver ion.

Reaction of l-β-n-*Octyl Bromide with Silver Oxide in 60% Aqueous Alcohol at the Boiling Point.*—The bromide (15 g.) was treated with silver oxide (30 g.) in the boiling solvent, which was prepared by mixing 6 vols. of purified anhydrous ethyl alcohol with 4 vols. of water. After 2 days the silver salts were filtered off, and washed first with ethyl alcohol and then with light petroleum. The organic materials were extracted with light petroleum, and, after the removal of most of the solvent, treated with sufficient bromine to convert the octene into dibromo-octane. The octyl alcohol and ethyl octyl ether were then isolated together by distillation. The former was converted into its acid phthalic ester by treatment with phthalic anhydride at 110—115°, and the neutral and acid products were separated with the aid of ether and sodium carbonate. The neutral product, *ethyl β-n-octyl ether*, had b. p. 68°/18 mm. (1·5 g.) (Found: C, 76·0; H, 13·9. Calc.: C, 75·9; H, 14·0%). The hydrogen phthalate (4·65 g.) had $[\alpha]_D^{20^\circ}$ + 26·04° in dry ethyl-alcoholic solution, and this allows us to calculate the rotation given in Table I for the alcohol.

TABLE II.

Reaction of β-n-Octyl Bromide with Silver Oxide in 63% Alcohol.

At the boiling point.

(a) $1{\cdot}27(Ag_2O)_{1/2}$.		(b) $3{\cdot}16(Ag_2O)_{1/2}$.		(c) $1{\cdot}27(Ag_2O)_{1/2} + 1{\cdot}00AgBr$.	
Time (min.).	Reaction (%).	Time (min.).	Reaction (%).	Time (min.).	Reaction (%).
5·0	9·7	4·8	26·6	5·0	19·9
10·0	19·2	7·0	31·1	10·0	36·8
18·1	37·3	12·7	53·7	18·0	53·4
29·8	56·8	17·6	63·3	30·0	74·4
45·0	73·3	20·6	71·3	45·0	84·2
209·0	96·7	26·0	76·4	70·0	95·4

At 35°.

(d) $1{\cdot}25(Ag_2O)_{1/2}$.		(e) $5{\cdot}00(Ag_2O)_{1/2}$.	
Time (min.).	Reaction (%).	Time (min.).	Reaction (%).
226·0	28·0	55·0	17·3
451·0	45·4	156·0	38·8
2711·0	93·4	225·0	55·0
4296·0	94·5	463·0	82·7
		1218·0	95·4

Rate of Reaction of β-n-Octyl Bromide with Soluble Silver Salts in 63% Aqueous Alcohol.—Two parallel experiments (*f* and *g*) were carried out at 35° with solutions initially 0·0285*M* with respect to β-*n*-octyl bromide and 0·0357*M* with respect to silver nitrate. In one of these experiments (*g*) silver bromide was suspended in the solution in quantity equivalent to 1 mol. per mol. of octyl bromide.

Two further experiments were performed at 35° with solutions originally 0·0100*M* with respect to β-*n*-octyl bromide and 0·0116*M* with respect to silver. The reagent was in the one case (*h*) silver nitrate and in the other (*i*) silver acetate.

TABLE III.

Reaction of β-n-Octyl Bromide with Silver Nitrate and Acetate in 63% Aqueous Alcohol at 35°.

(f) $1{\cdot}25AgNO_3$.		(g) $1{\cdot}25AgNO_3 + 1{\cdot}00AgBr$.		(h) $1{\cdot}16AgNO_3$.		(i) 1·16AgOAc.	
Time (min.).	Reaction (%).	Time (min.).	Reaction (%).	Time (min.).	Reaction (%).	Time (min.).	Reaction (%).
5·5	2·7	4·2	4·7	24·0	1·3	19·5	3·9
14·5	11·8	9·0	10·9	60·0	9·1	60·0	11·0
32·0	24·7	16·0	18·7	127·5	20·1	114·0	16·9
45·5	31·3	27·0	27·5	188·5	27·1	172·0	25·3
67·7	42·8	47·0	40·5	244·5	34·9	211·0	29·6
105·5	57·4	67·0	49·6	321·5	41·7	305·0	38·4
145·0	69·3	87·0	56·9	473·5	54·3	424·0	45·6
182·7	74·7	107·0	62·9	620·0	61·1	612·0	53·6
217·5	77·8	146·5	72·9	1265·0	80·8	1216·0	67·5
256·2	83·2	212·0	82·9	1511·0	83·2	1542·0	71·7
		274·5	88·6	2076·0	88·3	2070·0	74·9
				2727·0	92·7	2846·0	83·5

Reaction of l-β-n-Octyl Bromide with Silver Nitrate in 63% Aqueous Alcohol.—The bromide (8·2 g.) and a solution of silver nitrate (8·7 g.) in the aqueous-alcoholic solvent (100 c.c.) were together added to 1 l. of the solvent at 35°. After 2 hours a further quantity of bromide (8·2 g.) was added, and at the same time a further amount of silver nitrate (8·7 g.), previously dissolved in 100 c.c. of the solvent. After a further 18 hours had been allowed for completion of the reaction, the mixture was worked up for the organic products as described for the similar experiment with silver oxide as reagent. Octylene (1·3 g.) was removed by distillation, octyl alcohol was isolated as its hydrogen phthalate (8 g.), and ethyl octyl ether and octyl nitrate were obtained together and subsequently separated as well as possible by distillation; the ether was finally purified (1·5 g.) by distillation after being heated under reflux with metallic sodium. The hydrogen phthalate had $[\alpha]_D^{18°}$ + 33·47° in ethyl alcohol; the other rotations are given in Table I.

Reaction of l-β-n-Octyl Bromide with Silver Acetate in 63% Aqueous Alcohol.—Owing to the limited solubility of silver acetate in the solvent, the reagents were added in eight equal

portions, the additions being timed to keep pace with the reaction. The reaction was started at 35°, but it was found to be very slow, and was completed at the b. p. Each addition to the medium (1 l.) consisted in 1·82 g. of silver acetate, which, after dissolution, was followed by 2·05 g. of β-*n*-octyl bromide. The products, worked up as usual, gave β-*n*-octyl hydrogen phthalate (6 g.) having $[\alpha]_D^{20°}$ + 10·58° in ethyl alcohol, ethyl β-*n*-octyl ether (b. p. 65°/16 mm., yield 1·6 g. after purification by heating with sodium), and small amounts of octylene (0·7 g., b. p. 85°/17 mm.) and α-*n*-octyl acetate (not purified).

Reaction of l-α-Phenylethyl Chloride with Aqueous Acetone [with A. D. SCOTT].—(i) The solvent (1200 c.c.) was a mixture of 6 vols. of purified acetone and 4 vols. of water. A solution of the chloride (6·5 g.) in this solvent was digested with silver oxide (6·5 g.) at 70° for 6 hours. The product was isolated by extraction with ether, shown to be free from halogen and from styrene, and distilled, b. p. 98°/19 mm. (3·0 g.) (Found : C, 77·9; H, 8·3. Calc. for α-phenylethyl alcohol : C, 78·7; H, 8·2%).

(ii) The solvent (300 c.c.) was a mixture of 8 vols. of purified acetone and 2 vols. of water. A solution of the chloride (6·5 g.) in this solvent was digested with silver oxide (6·5 g.) at 70° for 44 hours. The alcohol, b. p. 99°/20 mm. (3·0 g.), was isolated as before.

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256. *Reaction Kinetics and the Walden Inversion. Part V. Action of Silver Salts in Hydroxylic Solvents on α-Bromopropionic Acid, its Methyl Ester, and Sodium Salt.*

By WILLIAM A. COWDREY, EDWARD D. HUGHES, and CHRISTOPHER K. INGOLD.

The stereochemical study of the reactions of halides with silver salts in hydroxylic media is here extended to halides with either a formally neutral or an ionic modification of the carboxyl group (·CO_2Me, ·CO·NH_2; or ·CO_2^-) in attachment to the seat of substitution. The silver salts included silver nitrate in solution and silver oxide in suspension; the halogen compounds were derivatives of α-bromopropionic acid, which was used in the form of its methyl ester, the acid itself or its silver salt, and its sodium salt. However it was shown kinetically that when either the acid or one of its salts is employed the entity substituted is essentially the α-bromopropionate ion, so that effectively we have only two cases to consider, characterised respectively by the attachment of a substituted carboxyl group, and a carboxylate ion group, at the asymmetric centre. It was also proved kinetically that the reagent supplied by silver nitrate is silver ions adsorbed on silver bromide, whilst with silver oxide the attack is by silver ions on both silver bromide and silver oxide.

The optical data relate to the methoxylation of the methyl ester with silver nitrate, and the hydroxylation of the amide with silver carbonate, and of the anion with silver nitrate, carbonate, and oxide. With the ester and amide the predominating orientation was inversion, whilst with the anion it was retention of form; but in all cases there was definite racemisation. Quantitative particulars are given. The results of Parts IV and V resemble those obtained for homogeneous unimolecular substitution (Parts I—III).

THE aim of the work here reported is to establish the spatial orientation of the hydroxylation and alkoxylation of α-halogeno-carboxylic acids and their derivatives when these substitutions are carried out by means of silver salts in the presence of aqueous or alcoholic media. As examples of silver salts we have employed silver nitrate in solution and silver oxide in suspension. As halogen compounds we have used derivatives of one of the simplest optically resolvable halogeno-acids, *viz.*, α-bromopropionic acid, which was employed as such or in the form of its methyl ester or silver or sodium salt; but we shall show that when either the acid or one of its salts is used the entity substituted is essentially the α-bromopropionate ion; so that effectively we have to consider only two cases, typified respectively

by the attachment of a carbomethoxyl group and a carboxylate ion group to the atom at which substitution occurs. We shall treat these cases separately, as the results are rather distinct. The reactions examined were the methoxylation of the methyl ester by means of silver nitrate in methyl-alcoholic solution; and the hydroxylation of the anion, either by aqueous silver nitrate, or by silver oxide suspended in water or aqueous acetone.

(1) *The Ester (and an Amide).*—A kinetic study of the action of silver nitrate in alcoholic solution on methyl bromoacetate and several homologues has been recorded by Senter (J., 1911, **99**, 95). He observed heterogeneous catalysis by silver bromide, although this effect seemed less powerful than in corresponding experiments with the free acids; and his results could be represented in terms of second-order constants which tended to decrease as reaction progressed. Our more restricted experiments with methyl α-bromopropionate and silver nitrate in methyl alcohol as solvent confirm Senter's. With both solutes originally in 0·16*M*-concentration, the period of half-change at 64° was 4·7 hours, and the approximate second-order rate constant 0·0005 $sec.^{-1}$ $g.-mol.^{-1}$ l. Since, even at 100°, the homogeneous reaction of the bromo-ester with methyl alcohol, independently of silver salts, has a first-order rate constant of only 0·00000295 $sec.^{-1}$, corresponding to a half-change period of 67 hours (Part III), this process must be quite negligible in comparison with the reaction of the bromo-ester with silver nitrate. The silver nitrate reaction evidently involves a heterogeneous attack by silver ions on bromo-ester adsorbed on silver bromide; but it is rather more likely here than in some other reactions of silver salts with halides that there is also a homogeneous attack by silver ions, although any rigorous proof of this would be difficult to devise.

The optical effect of the substitution is shown by the following experiment. A methyl-alcoholic solution, originally 0·16*M* with respect to methyl *d*-α-bromopropionate and 0·166*M* with respect to silver nitrate, was kept at 64° for 7 days, a time amply sufficient to complete the decomposition. The product, a mixture of methyl α-methoxypropionate and *methyl α-nitratopropionate*, was separated into its constituents by distillation. The rotations were as follows *:

$$(\alpha_D^{20^\circ} + 31{\cdot}8^\circ)\ CH_3{\cdot}CHBr{\cdot}CO_2Me \xrightarrow[\text{in MeOH}]{AgNO_3} \begin{cases} CH_3{\cdot}CH(OMe){\cdot}CO_2Me\ (\alpha_D^{17^\circ} - 36{\cdot}4^\circ) \\ CH_3{\cdot}CH(ONO_2){\cdot}CO_2Me\ (\alpha_D^{17^\circ} - 35{\cdot}9^\circ) \end{cases}$$

As was shown in Part III, an inversion in the sign of rotation on passing from the bromo-ester to the methoxy-ester means an inversion of configuration. The maximal rotatory powers (α_D) of these two esters being 74° and 95° respectively, the retention of activity in the substitution amounts to 89%. Presumably the inverted sign of rotation of the nitrato-ester also signifies an inversion of configuration, but this relationship has not been independently established, nor has the maximal rotatory power of the nitrato-ester been determined.

Considerations of analogy and theory suggest that amides should behave quite similarly to esters with respect to the property we are concerned to investigate; but we have not carried out a similar study with a representative amide because this case is really covered by an experiment performed by E. Fischer (*Ber.*, 1907, **40**, 489). He effected the hydroxylation of *l*-α-bromopropionylglycine by means of silver carbonate and water, and observed an optical effect which we can recognise as indicating a predominating inversion of configuration: the original glycine was prepared from *l*-α-bromopropionic acid and the final glycine hydrolysed to *d*-lactic acid †:

$$l\text{-}CH_3{\cdot}CHBr{\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO_2H \xrightarrow[H_2O]{Ag_2CO_3} d\text{-}CH_3{\cdot}CH(OH){\cdot}CO{\cdot}NH{\cdot}CH_2{\cdot}CO_2H$$

The retention of activity observed by Fischer may be estimated from his data as 73%, but his technique was unsuitable for quantitative work: he converted the lactylglycine into lactic acid, and, for polarimetric examination, isolated crystalline zinc lactate, which, owing to its considerable solubility, was obtained in poor yield, and doubtless with some

* All rotations relate to $l = 10$ cm. unless otherwise specified.

† This is the lævorotatory acid which gives dextrorotatory salts and esters: Fischer calls it *l*-lactic acid.

preferential separation of either the principal enantiomeride or the racemate. However, there can be no doubt about the qualitative orientational similarity between our alkoxylation of the ester and his hydroxylation of the amide, through the agency of silver salts.

(2) *The Acid and its Salts.*—The kinetics of the hydroxylation of α-halogeno-acids by means of silver nitrate in aqueous solvents have been studied by several authors. Euler (*Ber.*, 1906, **39**, 2726) examined the reaction between chloro- and bromo-acetic acid on the one hand, and aqueous or aqueous-alcoholic silver nitrate on the other; and found that calculated second-order rate constants decreased as substitution progressed, owing, as he deduced, to the circumstance that most of the reaction went through the small proportion of chloro- or bromo-acetate ion, which the liberated nitric acid progressively suppressed. Senter (J., 1910, **97**, 346), studying the reactions of bromoacetic acid and several of its homologues with aqueous silver nitrate, discovered the heterogeneous catalysis by silver bromide, and confirmed Euler's conclusion concerning the greater reactivity of halogeno-anions than of the corresponding undissociated acids. Euler and Ölander (*Z. Elektrochem.*, 1930, **36**, 506) experimented with sodium bromoacetate and aqueous silver nitrate, but even under these conditions bromoacetate ions must become partly replaced by bromoacetic acid molecules, owing to the liberation of nitric acid as reaction proceeds; and no simple kinetic order was found. Finally Kappanna (*Proc. Indian Acad. Sci.*, 1935, **2**, 512), working with sodium α-bromopropionate and aqueous silver nitrate, confirmed Senter's observation of the catalysis by silver bromide, observed a period of induction in the absence of initially added silver bromide, and an accelerated rate up to the point at which the formed silver bromide coagulated.

As it was necessary for the interpretation of our optical experiments to confirm the hypothesis of reaction through the halogeno-anion, we carried out rate measurements of the reaction between α-bromopropionic acid and aqueous silver nitrate in the presence of various concentrations of initially added nitric acid. Lacking a precise reaction order, it is not possible accurately to express ratios of rates numerically; but we show that when the hydrion concentration is increased several-fold, so that the concentration of the bromopropionate ion is decreased correspondingly, the rate decreases by approximately the same factor. For example, when the mean hydrion concentration was increased from 0·143 to 1·08*N* and 2·04*N*, *i.e.*, by factors of 7·5 and 14 respectively, the mean rate, calculated as an approximate second-order constant, became decreased by factors of 7 and 12 respectively. This shows that, even in rather strongly acid solutions (*e.g.*, *N*), the reaction goes almost entirely through the anion.

Summarising, we may conclude that, whether we employ the bromo-acid or one of its salts, the reaction with silver nitrate consists essentially in an attack by silver ions on bromo-anions adsorbed on silver bromide.

The reactions of α-halogeno-acids with suspended silver oxide involve certain differences of behaviour. If the silver salt of the halogeno-acid is at all readily soluble, the rate of hydroxylation by means of silver oxide and water is much greater when the free acid is used than when a salt is employed. This is notably true, as we have shown by qualitative observations, for α-bromopropionic acid and its sodium salt; the difference is opposite in direction to that found when the reagent is silver nitrate. This does not mean that with silver oxide the reaction no longer proceeds through the halogenated anion: it is due merely to the circumstance that the first action of the free bromo-acid on silver oxide is to dissolve some of it, thus building up a much greater concentration of silver ions in solution than would have been produced by the suspended silver oxide in the absence of an acidic substance.

The essentially specific effect of silver oxide is best brought out by following its reaction with a salt of the halogeno-acid. The one previous investigation of this kind, that of Euler and Fahlander (*Z. physikal. Chem.*, 1922, **100**, 171), who used aqueous sodium bromoacetate, showed that the reaction-rate increased with the quantity of suspended silver oxide. Employing sodium α-bromopropionate, we have proved the heterogeneous catalysis by silver bromide, and confirmed the dependence of the rate on the excess of silver oxide. The two effects are illustrated by the reaction-time curves of the figure.

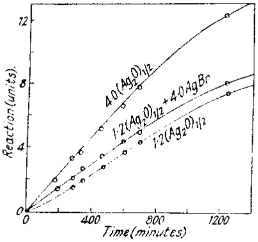
All these phenomena so closely correspond with those observed for alkyl halides that

we may surely generalise the conclusion reached in Part IV, *viz.*, that, whether the reagent is a soluble silver salt or a suspension of silver oxide, the attack on the halogen compound is by silver ions adsorbed on silver halide, and also on silver oxide if any is present. The new point which arises is that the anions of α-halogeno-acids are very much more susceptible to attack by silver ions than are the acids themselves. In this respect the silver reaction resembles homogeneous unimolecular substitution (S_N1); and we shall find a further analogy between the two processes in the stereochemical results now to be described.

The following experiment shows the optical effect accompanying the hydroxylation of α-bromopropionic acid by the action of aqueous silver nitrate. A solution, initially 0·10*M* with respect to both *d*-α-bromopropionic acid and nitric acid, and 0·11*M* with respect to silver nitrate, was stirred at 50° for 15 hours, a period more than sufficient to ensure the completion of the reaction, and the lactic acid produced was converted into its ethyl ester. The following rotations were observed :

$$(\alpha_D^{19°} + 9{\cdot}90°)\ CH_3{\cdot}CHBr{\cdot}CO_2H \xrightarrow[\text{(and esterification)}]{AgNO_3 + HNO_3 + H_2O} CH_3{\cdot}CH(OH){\cdot}CO_2Et\ (\alpha_D^{19°} + 2{\cdot}02°)$$

As shown in Part III, a retention of the sign of rotation in the hydroxylation and esterification indicates a retention of configuration in the substitution. The maximal rotatory powers of the factor and product being 49° and 11·5° respectively, we can calculate that optical activity is preserved to the extent of 87%.



The action of silver carbonate in aqueous suspension on optically active α-bromopropionic acid was studied by E. Fischer (*loc. cit.*). He observed an optical effect which can be recognised as indicating also a retention of configuration, although with considerably more accompanying racemisation than arises with the use of silver nitrate: roughly estimated, the retention of activity amounted to about 36%. We have studied the action of silver oxide on optically active α-bromopropionic acid, and also on its sodium salt, under various conditions. In all cases configuration was preserved, but the retention of optical activity varied in the different experiments over the range 28—58%. Probably one should expect some such variation owing to the presence of two catalytically active surfaces, the relative efficacies of which are difficult to control and are probably sensitive to the precise conditions of experiment. The following record will serve as an illustration of our procedure. A 0·25*N*-aqueous solution of sodium *d*-α-bromopropionate was stirred with 1·2 equivs. of silver oxide at 0°. After the reaction had been carried to completion the lactic acid was esterified with ethyl alcohol. The observed rotations correspond to a 58% preservation of optical activity.

$$\begin{array}{ccc} (\alpha_D^{18°} + 10{\cdot}18°)\ CH_3{\cdot}CHBr{\cdot}CO_2H & & CH_3{\cdot}CH(OH){\cdot}CO_2Et\ (\alpha_D^{18°} + 1{\cdot}40°) \\ \downarrow & & \uparrow \\ CH_3{\cdot}CHBr{\cdot}CO_2Na & \xrightarrow{Ag_2O + H_2O} & CH_3{\cdot}CH(OH){\cdot}CO_2Na \end{array}$$

(3) *Results.*—Without entering into the details of the remaining experiments, we collect together the essential results in Table I, in which are included the two experiments

by E. Fischer already mentioned. Cols. 1—5 show the materials used, their proportions, the solvent and the temperature; col. 6 indicates the nature of the substitution; cols. 7—9 give the observed rotations; and the final col. the percentage retention of optical purity. The signs in col. 10 indicate whether configuration has been preserved (+) or inverted (—).

TABLE I.

Optical Effects in Reactions between Silver Salts and α-Bromopropionic Acid Derivatives.

X in *CHMeBrX.*	Re-*agent.*	Equivs. *Ag.*	*Solvent.*	*Temp.*	Entrant group, *R.*	α_D *Halide.*	α_D CHMeR·CO_2*Me.*	α_D CHMeR·CO_2*Et.*	Retention optical purity, %.
CO·OMe	$AgNO_3$	1·04	MeOH	64°	OMe	+31·8°	−36·4°	—	−89
					ONO_2	+31·8	−35·9	—	—
CO·NHA†	Ag_2CO_3	excess	H_2O	room	OH	—	—	—	−73 *
CO·OH	$AgNO_3$	1·1	aq.-HNO_3	50	,,	+ 9·9	—	+2·02	+87
,,	Ag_2CO_3	2·2	H_2O	0	,,	—	—	—	+36 *
,,	Ag_2O	1·2	,,	0	,,	+10·0	—	+1·07	+45
,,	,,	2·1	,,	0	,,	+ 9·8	—	+0·65	+28
,,	,,	10·0	,,	0	,,	+19·5	—	+1·56	+34
,,	,,	2·1	aq.-Me_2CO	0	,,	+10·0	—	+1·24	+53
CO_2Na	,,	1·2	H_2O	0	,,	+10·2	—	+1·40	+58
,,	,,	1·1	aq.-Me_2CO	0	,,	+10·0	—	+1·17	+50

* Experiments by E. Fischer (*loc. cit.*), who isolated the lactic acid incompletely as zinc lactate; wherefore the figures given are subject to the error mentioned on p. 1244.

† A = $CH_2·CO_2H$. Purdie and Williamson (J., 1896, **69**, 837) hydrolysed *d*-α-chloropropionic acid by means of silver oxide and water, and obtained a partly racemised zinc lactate with a retained sign of rotation.

SUMMARY.

(Covering Parts IV and V.)

Recalling the kinetic evidence that, even under more acidic conditions than any used in these experiments with optically active material, practically the whole of the reaction of the free carboxylic acid takes place by way of its anion, we can summarise these results in a more compact form by relating the observed effect to the entity which actually undergoes the substitution. This is done in the lower section of Table II, in the upper part of which we give a similar summary of the results of the preceding paper, in order to bring the whole of the evidence concerning the silver reaction into a single conspectus. The entries in the column headed "reagent" show, in order, the silver ion, the catalytic surface or surfaces on which it attacks the "halide substituted" (col. 2), and the solvent molecule which completes the substitution. The headings of the remaining columns are self-explanatory.

TABLE II.

Optical Effects in the Reactions of Halogen Compounds with Silver Salts.

Paper.	Halide substituted.	Reagent.		Approx. temp.	Entrant group.	Effect on configtn.*	Optical purity, %.
IV	Me, H >C< C_6H_{13}, Br	Ag^+ + AgBr	+ H_2O	35—80°	OH	I + Ra	72
		Ag^+ + AgBr	+ EtOH	35—80	OEt	,,	94
		Ag^+ + AgBr + Ag_2O	+ H_2O	80	OH	,,	74
		Ag^+ + AgBr + Ag_2O	+ EtOH	80	OEt	,,	94
	Me, H >C< C_6H_5, Cl	Ag^+ + AgCl + Ag_2O	+ H_2O	20—70	OH	,,	3—29
V	Me, H >C< CO·OMe, Br	Ag^+ + AgBr	+ MeOH	64	OMe	,,	89
	Me, H >C< CO·NHA, Br	Ag^+ + AgBr + Ag_2CO_3	+ H_2O	room	OH	,,	*ca.* 73
	Me, H >C< CO_2^-, Br	Ag^+ + AgBr	+ H_2O	50	,,	Re + Ra	87
		Ag^+ + AgBr + Ag_2CO_3	+ H_2O	0	,,	,,	*ca.* 36
		Ag^+ + AgBr + Ag_2O	+ H_2O	0	,,	,,	28—58

* I = Inversion; Ra = racemisation; Re = retention.

The principal conclusions to be derived from an inspection of this table would appear to be the following. (1) The reactions of all the halogen compounds with all the silver salts in all the solvents used involve definite racemisation; and if a phenyl group is attached to the seat of substitution the amount of racemisation is particularly great. (2) When, in addition to a hydrogen atom and a methyl group, a hexyl, phenyl, carboxylic ester, or carboxylamide group is attached to the seat of substitution, the predominating orientation is an inversion; but, when the asymmetric atom bears a carboxylate ion group, then the predominating stereochemical effect is retention of the original configuration. The work described in the present paper brings out clearly the contrast between the orienting effect of the non-ionised carboxyl substituents ·CO·OR and ·CO·NHR on the one hand and the ionic substituent $\cdot CO_2^-$ on the other. In Part III we exposed a quite similar contrast between the non-ionised forms ·CO·OR and ·CO·OH, which also lead to predominating inversion, and the ionic group $\cdot CO_2^-$, which again causes retention of configuration, in homogeneous unimolecular substitution (S_N1). This stereochemical parallel constitutes further evidence of an analogy of mechanism, already indicated by the similar effects of structure on the rates of the S_N1-reaction and the silver reaction.

It can also be seen from Table II that, although the quantitative data are very various, the qualitative stereochemical result of substitution with the aid of silver ions is independent, first, of whether the reaction studied is hydroxylation, methoxylation, or ethoxylation, and secondly, of whether the active surface available to the silver ions is silver chloride or bromide, or one of these together with silver carbonate or oxide. This enables us to express the main outcome of the investigation described in both the previous paper and this one in the condensed form adopted in Table III. This table is cast into the same form as Table IV of Part III (this vol., p. 1224), and the two together epitomise the empirical knowledge thus far obtained concerning the relationship between steric course of the replacements of ·Hal by ·OR on the one hand, and the structure of the reagents and mechanism of the reactions on the other. A comparison of the two tables clearly shows the analogy between the homogeneous unimolecular and the heterogeneous mechanisms.

TABLE III.

Steric Course of the Heterogeneous Replacement of ·Hal *by* ·OR.

X in CHMeX·Hal.	Effect on configuration (silver reaction).
C_6H_{13}	Racemisation + inversion
C_6H_5	Large racemisation + inversion
CO·OR, CO·NHR	Racemisation + inversion
CO_2^-	Racemisation + retention

EXPERIMENTAL.

Materials.—The sources of the optically active and racemic halogen compounds were as stated in Part III. Concerning the reagents, the only noteworthy point is that silver oxide was prepared by precipitation from a solution containing a small excess of silver ions. The reason for this is that hydroxide ions are rather strongly adsorbed on silver oxide; so that, when silver oxide is precipitated from a solution containing an excess of alkali, there is danger of its carrying down hydroxide ions, which, by the rule of solubility products, must alter the solubility of the oxide with respect to silver ions, on which its activity as a reagent partly depends. Naturally, oxide required for several comparative kinetic experiments, or for a kinetic experiment and a parallel optical investigation, was prepared in a single batch.

Rate of Reaction of Methyl dl-*α-Bromopropionate with Silver Nitrate in Methyl Alcohol at 64°.*—A solution of methyl α-bromopropionate (7·953 g.) in 0·159*N*-methyl-alcoholic silver nitrate (300 c.c.) was sealed up in portions of 10 c.c. in glass bulbs, which were heated for known times at 64·0°, the silver-ion content being estimated thereafter by titration with ammonium thiocyanate. An estimation made after heating a bulb for 30 minutes was treated as a value corresponding to zero time. Titrations made after " infinite " time showed that the bromo-ester and silver nitrate had been in exactly equivalent proportion: when silver ions were no longer present no bromide ions could be obtained by hydrolysis with sodium hydroxide. In the following table, $a - x$, the concentration of unreacted bromo-ester, is expressed in c.c. of the thiocyanate solution per 10 c.c. sample of the reaction mixture. The value of a, given as

32·40 c.c., is 0·1203*N*, after correction for thermal expansion, the factor for which was taken as 0·94. In order to provide a rough measure of the rate, second-order " constants " (min.$^{-1}$ g.-mol.$^{-1}$ l.) have been calculated, although they have no definite chemical meaning in relation to the heterogeneously catalysed reaction :

t (min.)	0	30	90	102	180	270	310	452	727	870	1188
$a - x$ (c.c.)...	32·40	29·20	24·10	23·50	19·40	16·50	14·90	12·60	9·28	8·15	6·80
10^2k_2	—	3·02	3·18	3·08	3·09	2·96	3·14	2·90	2·85	2·84	2·80

A few estimations of the acidity were made. The values obtained were equivalent to only about 70% of the consumption of silver ions. The difference measures the formation of methyl α-nitratopropionate, simultaneously with the main products, which are methyl α-methoxypropionate and nitric acid. This is shown by the isolation of the nitrato- as well as the methoxy-ester (below).

Reaction of Methyl d-*α-Bromopropionate with Silver Nitrate in Methyl Alcohol at* 64°.—A solution of the ester (30·06 g.), $\alpha_D^{20°}$ + 31·8°, in a methyl-alcoholic solution of silver nitrate (31·0 g.) was made up to 1100 c.c. with dry methyl alcohol, and kept at 64° for 7 days. Test portions, examined for silver ions and bromo-ester (production of bromide ions by hydrolysis with alkali), showed that the former were present only in small amount, whilst the latter was wholly absent. Another test portion was freed from silver ions with sodium bromide, and examined for acidity by titration with methyl-alcoholic sodium methoxide; the result showed that 36% of the bromo-ester had been converted into nitrato-ester, and the remainder into methoxy-ester (see above). Methyl-alcoholic sodium bromide was added to the main part of the solution to precipitate the excess of silver, and the filtrate from the silver bromide was neutralised with methyl-alcoholic sodium methoxide. The methyl alcohol was removed by distillation through an efficient column, and the salts separated by filtration. Ether was added finally to precipitate the salts, and, after evaporation, the residual esters were fractionated under reduced pressure. Two pure fractions were obtained. The first, methyl α-methoxypropionate, had b. p. 43°/20 mm., and $\alpha_D^{17°}$ − 36·44° (Found : C, 50·65; H, 8·45. Calc. : C, 50·8; H, 8·53%). The second, ***methyl α-nitratopropionate***, had b. p. 74·5°/17 mm., $\alpha_D^{17°}$ − 35·90° (Found : N, 9·4. $C_4H_7O_5N$ requires N, 9·4%).

Rate of Reaction of dl-*α-Bromopropionic Acid with Silver Nitrate in Dilute Aqueous Nitric Acid at* 50°.—Three experiments were carried out with the following approximate initial concentrations of reagents :—

No.	HNO_3.	$NaNO_3$.	Bromo-acid.	$AgNO_3$.
11	0·1*N*	—	0·10*M*	0·15*M*
12	1·0*N*	1·0*M*	0·25*M*	0·37*M*
13	2·0*N*	—	0·25*M*	0·37*M*

The details of the preparation of the solutions are as follows. (11) An aqueous solution of the bromo-acid (3·837 g.) was added to a mixture of 0·2000*N*-silver nitrate solution (187·5 c.c.) and 0·6624*N*-aqueous nitric acid (38·00 c.c.). The separate solutions were raised to 50° before being mixed, and the mixture was made up to 250 c.c. at the same temperature. (12) A solution of the bromo-acid (9·50 g.) in water was added to a solution made from silver nitrate (15·95 g.), sodium nitrate (20·5 g.), 2·408*N*-aqueous nitric acid (100 c.c.), and water (50 c.c.). The solution was made up to 250 c.c. at 50° as before. (13) An aqueous solution of the bromo-acid (9·574 g.) was added to a solution of silver nitrate (15·94 g.) in 2·408*N*-aqueous nitric acid (100 c.c.), and the mixture made up to 250 c.c. at 50°.

The results are in Table IV. The values of $b - x$, the concentration of unreacted silver ions, are expressed in c.c. of 0·1000*N*-ammonium thiocyanate solution per 10 c.c. sample. In the same units, the value of b, the initial concentration of silver ions, is given by the first entry under $b - x$, whilst a, the initial concentration of bromo-acid, is represented by the difference between the first and last entries. In order to provide the data for conversion of the concentrations into absolute units, a and b are re-expressed as normalities. As a convenient, if arbitrary, measure of the reaction rate, second-order " constants " (min.$^{-1}$ g.-mol.$^{-1}$ l.) have been calculated. The mean rates are roughly inversely proportional to the mean concentration of hydrogen ions, which in the introduction is computed by adding half the initial concentration of bromo-acid to the initial concentration of nitric acid, in order to allow for extra nitric acid produced in the course of reaction.

Reaction of d-*α-Bromopropionic Acid with Silver Nitrate in Dilute Aqueous Nitric Acid at* 50°.—The conditions were chosen approximately to correspond to expt. 11 (preceding paragraph). A solution of the bromo-acid (16·30 g.), $\alpha_D^{19°}$ + 9·90, in water (264 c.c.) was mixed at

TABLE IV.

Expt. 11 $\begin{cases} a = 0{\cdot}0856N \\ b = 0{\cdot}1378N \end{cases}$			Expt. 12 $\begin{cases} a = 0{\cdot}2265N \\ b = 0{\cdot}3595N \end{cases}$			Expt. 13 $\begin{cases} a = 0{\cdot}2320N \\ b = 0{\cdot}3640N \end{cases}$		
t (min.).	$b - x$.	10^2k_2.	t (min.).	$b - x$.	10^2k_2.	t (min.).	$b - x$.	10^2k_2.
0·00	13·78	—	0·00	35·95	—	0·00	36·40	—
2·83	12·90	31·0	5·53	34·00	4·68	9·58	34·25	2·86
6·95	11·65	32·9	10·47	32·35	4·87	16·67	32·80	3·00
11·75	10·60	33·1	16·95	30·50	5·03	23·75	31·50	3·00
17·42	9·65	33·1	25·0	28·60	4·95	34·92	29·75	2·94
23·55	8·75	35·2	32·0	27·30	4·87	46·2	28·15	2·99
31·25	7·95	36·3	42·4	25·30	5·06	57·5	26·80	3·02
44·17	7·10	36·9	52·2	24·00	5·00	70·0	25·65	2·98
66·5	6·30	37·1	67·7	22·25	5·00	84·7	24·40	2·95
106·7	5·65	37·7	89·0	20·50	4·96	100·0	23·20	2·97
195·6	5·30	—	187·0	16·30	4·96	126·0	21·65	2·96
"∞"	5·22	—	212·0	15·80	4·91	150·0	20·55	2·91
			292·0	14·55	5·14	180·5	19·35	2·92
Mean (Expt. 11)		34·8	"∞"	13·30	—	229·0	17·90	2·95
,, (Expt. 12)		4·95				285·0	16·85	2·88
,, (Expt. 13)		2·95				"∞"	13·20	—

50° with an aqueous 0·2000N-solution of silver nitrate (640 c.c.) and an aqueous 0·6624N-solution of nitric acid (161 c.c.). The mixture was stirred for 15 hours at 50°. The silver bromide was removed by filtration, and the excess of silver ion eliminated by the use of hydrochloric acid. The filtrate was neutralised with 2N-aqueous sodium hydroxide, made very slightly acidic, and evaporated to a small bulk. After the inorganic salts had been filtered off, 18N-sulphuric acid was added (15 c.c.), and the solution thoroughly extracted with ether, which dissolved the lactic acid and a certain amount of nitric acid. The ethereal extract was re-extracted with just sufficient dilute sodium hydroxide to make a neutral solution, which was evaporated and freed from sodium nitrate by the addition of dry ethyl alcohol. The sodium lactate was finally esterified by heating under reflux for 3 hours with ethyl alcohol (150 c.c.) and concentrated sulphuric acid (7 c.c.). Evaporation with additions of benzene, and extraction with ether after the addition of water, yielded ethyl lactate, which, on two distillations, gave a central fraction (3·80 g.) having b. p. 56°/15 mm., $\alpha_D^{19°}$ + 2·02°.

Reaction of d-α-*Bromopropionic Acid with Aqueous Suspensions of Silver Oxide at* 0°.—Three experiments were carried out with 1·2, 2·1, and 10·0 equivs. of silver oxide, the bromo-acid being in each case in approximately N/4-solution.

(Expt. 21) A solution of the acid (16·1 g.), $\alpha_D^{21°}$ + 10·05°, in water (320 c.c.) was stirred for 1 hour at 0° with a suspension of silver oxide (corresponding to 21·5 g. of silver nitrate) in water (100 c.c.). The mixture was kept for 2 days, and then filtered after the addition of excess of hydrochloric acid. Measured proportions of the filtrate were taken for tests. In one, the ionic halogen was estimated, and in a second, the total halogen (hydrolysis with sodium hydroxide, followed by titration with silver nitrate). The results showed that the bromo-acid has been substituted to the extent of 96·3%, and this was accepted as being sufficiently near to a complete reaction. The main solution was neutralised and evaporated to dryness, and the residue esterified as usual with ethyl alcohol. The fully rectified ethyl lactate (4·95 g.) had b. p. 56°/15 mm., $\alpha_D^{19°}$ + 1·07°.

(Expt. 22) The acid had $\alpha_D^{19°}$ + 9·82. The quantities were the same as before except that the silver oxide corresponded to 37·5 g. of silver nitrate. The mixture was stirred at 0° for 24 hours, reaction then being complete to within 3%. The rectified ethyl lactate had b. p. 56°/15 mm., $\alpha_D^{19°}$ + 0·65°.

(Expt. 24) A solution of the acid (15·32 g.), $\alpha_D^{20°}$ + 19·50°, in water (50 c.c.) was stirred at 0° for 30 mins. with a suspension in water (150 c.c.) of silver oxide prepared from 170 g. of silver nitrate. The mixture was kept overnight, and then worked up for ethyl lactate. The rectified ester (3 g.) had b. p. 53°/14 mm., $\alpha_D^{20°}$ + 1·56°. A parallel experiment (no. 23) with the *dl*-acid had shown that under these conditions the reaction is completed to within 3%.

Reaction of d-α-*Bromopropionic Acid with an Aqueous-acetone Suspension of Silver Oxide at* 0°.—The acid (15·33 g.), $\alpha_D^{20°}$ + 10·04°, was made up to 50 c.c. with a solution of water (5 c.c.) in acetone (95 c.c.). Silver oxide, prepared from 35·7 g. of silver nitrate, and well washed with water and then with acetone, was suspended in the remainder of the aqueous acetone. The materials were then mixed, stirred at 0° for 2 hours, and kept for 2 days. The product was worked up as usual for ethyl lactate. The rectified ester (3·9 g.) had b. p. 56·5°/15 mm., $\alpha_D^{20°}$ + 1·24°.

Rate of Reaction of Sodium dl-*α-Bromopropionate with Aqueous Suspensions of Silver Oxide at* 0°.—Three experiments were performed with the following approximate initial conditions :

No.	Na salt.	Ag_2O, equivs.	AgBr, equivs.
31	*N*/4	1·2	—
32	*N*/4	1·2	4·0
33	*N*/4	4·0	—

An aqueous solution of bromo-acid (38·4 g.) was almost neutralised with aqueous sodium hydroxide, and the mixture, kept very faintly acid to ensure absence of hydroxide ions, was made up to 1 l. Of this solution, 250 c.c. were used for each experiment. Silver oxide was prepared from 68 g. of silver nitrate by the addition of a slight excess of barium hydroxide and then a slight excess of silver nitrate, again to avoid hydroxide ions. The washed sludge weighed 89 g., and of this 16·7, 16·7, and 55·3 g. respectively were taken for the three experiments. The silver bromide, required for one experiment, was prepared immediately before use from silver nitrate (42·3 g.) and sodium bromide.

The reaction mixtures were all stirred mechanically at 0°, and at known times samples, each of about 12 c.c., were removed and filtered; and 10 c.c. of each filtrate were hydrolysed by boiling for 10 mins. with 2*N*-aqueous sodium hydroxide (10 c.c.). The hydrolysis solutions were diluted, and the bromide ion was estimated by titration with silver nitrate and ammonium thiocyanate. The progress of reaction, *x*, is expressed in Table V in c.c. of 0·1000*N*-ammonium thiocyanate for 10 c.c. of the reaction solution.

TABLE V.

Expt. 31.				Expt. 32.				Expt. 33.			
t (min.).	*x* (c.c.).	*t* (min.).	*x* (c.c.).	*t* (min.).	*x* (c.c.).	*t* (min.).	*x* (c.c.).	*t* (min.).	*x* (c.c.).	*t* (min.).	*x* (c.c.).
290	1·50	1500	9·18	186	1·38	1436	9·50	179	1·90	1487	14·20
350	1·90	1697	10·25	287	2·07	1694	10·25	279	3·30	1684	15·30
473	2·75	1918	11·55	344	2·65	1913	11·55	335	3·63	1906	17·00
602	3·65	2860	16·67	467	3·40	2859	15·80	457	5·15	2854	19·72
698	4·30	3270	18·35	596	4·30	3270	17·60	586	6·60	3264	20·65
1246	7·37	4340	20·55	694	4·90	4340	20·30	686	7·75	4335	21·45
1390	8·90			1240	8·00			1229	12·25		

Reaction of Sodium d-*α-Bromopropionic Acid with an Aqueous Suspension of Silver Oxide at* 0°.—A solution of the acid (15·90 g.), $\alpha_D^{18°}$ + 10·18°, in water was neutralised with 1·971*N*-aqueous sodium hydroxide (52·5 c.c.), and then made faintly acid. Silver oxide was prepared from silver nitrate (21·2 g.) in the presence of a small excess of silver ions, and suspended in water (113 c.c.). The materials were mixed at 0°, stirred mechanically for 92 hours, after which tests, such as have already been described, showed that reaction had proceeded to the extent of 94%. The product was worked up for ethyl lactate, the rectified specimen of which (4·9 g.) had b. p. 55°/13 mm., $\alpha_D^{19°}$ + 1·40°.

Rate of Reaction of Sodium dl-*α-Bromopropionate with an Aqueous-acetone Suspension of Silver Oxide at* 0°.—A solution of sodium α-bromopropionate (10·90 g.) in water (50 c.c.) was made up to 250 c.c. with acetone. Silver nitrate, prepared as usual from 9·4 g. of silver nitrate, was added at 0° to 200 c.c. of the solution of the sodium salt, and the suspension was stirred mechanically. Satisfactory results could not be obtained by filtration of the silver oxide and analysis of the filtrate, owing to the evaporation of the acetone during filtration; and therefore the following method was adopted. Each day the stirring was stopped for 1 hour, and 10 c.c. of the clear, supernatant solution were then removed. The sample was hydrolysed with sodium hydroxide, and the bromide ion determined. In each case 25 c.c. of 0·1001*N*-silver nitrate were added, the excess of silver ion being titrated with 0·09989*N*-ammonium thiocyanate. The excess of silver ion is expressed below in c.c. of thiocyanate solution per 10 c.c. sample. The last two readings correspond respectively to 94·5 and 98·0% of reaction :

Time (days)	0	1	2	3	5	6
Excess Ag^+	1·00	4·05	10·20	17·40	23·65	24·55

Reaction of Sodium d-*α-Bromopropionate with an Aqueous-acetone Suspension of Silver Oxide at* 0°.—The acid, $\alpha_D^{20°}$ + 10·0°, was converted into sodium salt by precipitation with sodium ethoxide in a mixture of ether and ethyl alcohol. A solution of the salt (17·27 g.) in

water (79 c.c.) was made up to 395 c.c. with acetone, and stirred mechanically for 6 days at 0° with silver oxide prepared from 18·7 g. of silver nitrate. The ethyl lactate isolated as usual had b. p. 57·5°/17 mm., $\alpha_D^{19°}$ + 1·17°.

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257. *Reaction Kinetics and the Walden Inversion. Part VI. Relation of Steric Orientation to Mechanism in Substitutions involving Halogen Atoms and Simple or Substituted Hydroxyl Groups.*

By W. A. COWDREY, E. D. HUGHES, C. K. INGOLD, S. MASTERMAN, and A. D. SCOTT.

The known relationships between the mechanism of aliphatic substitution and the structures of the compounds substituted form a starting point for the investigation of the laws governing the steric orientation of substitution. As a result of work reported in the preceding papers, certain general principles relating to the orientation of substitution are advanced. Detailed discussion is confined to the reciprocal replacements of ·Hal and ·OR, and within this field previously recorded stereochemical observations are to a large extent rationalised. A fuller statement of the conclusions is given on p. 1270.

NOTWITHSTANDING the large number of investigations that have been carried out since Walden's discovery of the inversion known by his name, much uncertainty still attaches to the rules and conditions that control the steric course of substitution at a saturated carbon atom. This is due partly to the difficulty of relating sign of rotation to molecular configuration. But a still more important cause is that the conditions controlling steric orientation are intimately dependent on the mechanism of substitution, and it is only within comparatively recent years that mechanism in aliphatic substitution has been fruitfully studied. In this field, mechanism has been elucidated principally through the examination of reaction kinetics, by means of which an intelligible relationship has been traced between mechanism, on the one hand, and the chemical structures of reactants, and the physical conditions of reaction, on the other. It was an obvious sequel to apply kinetics in order to elucidate the factors controlling the steric course of substitution; and the procedure has two advantages. First, we can often decide the steric orientation of a reaction by comparison on the basis of mechanism (which kinetic results help to establish) with some other reaction whose steric course is known. Secondly, it should be possible to establish an *empirical* connexion between steric orientation and kinetics; and thus, using our present knowledge of the relation of kinetics to mechanism, to link steric orientation with mechanism and its determining factors, chemical structure and physical conditions. We have therefore studied the optical effect of substitution at an asymmetric carbon atom under conditions, not chosen haphazard, but defined by parallel studies of kinetics. It is our view that much of the previous work on the Walden inversion requires repetition with this form of control (cf. Cowdrey, Hughes, and Ingold, *Nature*, 1936, 138, 759).

In the present paper we set forth conclusions based largely on the experimental studies recorded in the previous five papers. We deal here only with the reciprocal replacements of ·Hal and ·OR, and this only in a preliminary way : extensions of the study in this field, and likewise our investigations on the substitutions which involve $\cdot NR_2$, will be described in future groups of papers.

On the theoretical side our starting point is the general survey given by Hughes and Ingold (J., 1935, 244) of aliphatic substitution from the point of view of kinetics and mechanism. In section (A) we shall summarise such of the conclusions and applications of this theory as will be needed. It happens that one of the applications, one which we shall particularly require, was not mentioned in Hughes and Ingold's paper : this relates to the effect of modifications of the carboxyl group, including especially the carboxylate ion, on

the mechanism of substitution at an adjoining carbon atom. Accordingly, we include a fuller reference to this point than would otherwise have been necessary in the following preface to our stereochemical discussion.

(*A*) *Preliminary Remarks on Kinetics and Mechanism.*

(1) *General Principles.*—Reactions in which ·Hal is replaced by ·OR are " nucleophilic substitutions " : replacement is characterised by electron transfers from the reagent to the seat of substitution and from the latter to the extruded group. They are also classified as belonging to the " three-atom problem " : only one bond is broken and only one is formed —in short, one bond only is exchanged. For such substitutions two mechanisms are established. If the bond is exchanged in one act, the substitution is called bimolecular (S_N2); and in most cases it will be kinetically of the second order. Alternatively, if the bond is broken and reconstituted in separate acts, the substitution is said to be unimolecular (S_N1); and, if as usual bond-fission controls the rate, it will be kinetically of the first order. The two mechanisms are formulated for the example of hydrolysis :

$$\bar{O}H + Alk{\cdot}Hal \longrightarrow OH{\cdot}Alk + \bar{H}al \quad . \quad . \quad . \quad . \quad . \quad . \quad (S_N2)$$

$$\left.\begin{array}{l} Alk{\cdot}Hal \longrightarrow \overset{+}{A}lk + \bar{H}al \\ \overset{+}{A}lk + H_2O \longrightarrow Alk{\cdot}OH + \overset{+}{H} \end{array}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (S_N1)$$

Which of these mechanisms will operate in a given example depends *inter alia* on structure, *i.e.*, on the groups attached to the seat of substitution. Groups which withdraw electrons thereby facilitate the approach of the nucleophilic reagent, the presence of which is necessary for reaction by mechanism S_N2. Groups which supply electrons favour the dissociation, which is the rate-determining stage of mechanism S_N1. Our stereochemical argument will require the consideration of four kinds of groups, *viz.*, alkyl, aryl, carboxyl and carboxylate-ion groups, the effect of which on the mechanism of substitution will now be summarised.

(2) *Alkyl Groups.*—The replacements of ·Hal by ·OR in methyl halides is exclusively bimolecular (S_N2). Alkyl groups release electrons more strongly than hydrogen ; and hence the progressive replacement of the three hydrogen atoms in a methyl halide by alkyl groups will tend to replace mechanism S_N2 by mechanism S_N1. It is established that this happens (Hughes, J. 1935, 255; Hughes, Ingold, and Shapiro, J., 1936, 225; Hughes and Shapiro, this vol., pp. 1177, 1192 ; Cooper and Hughes, *ibid.*, p. 1183 ; Bateman and Hughes, *ibid.*, p. 1187) : in the replacement of ·Hal by ·OR in Alk·Hal, where Alk = Me, Et, Pr^{β}, Bu^{γ}, in aqueous or alcoholic solvents, reaction proceeds by mechanism S_N2, with successively diminishing speeds, in the first three members of the series ; and by mechanism S_N1, with increasing speeds, in the last two members ; in the third the two mechanisms are of comparable facility and operate side by side. The majority of known optically active halides are secondary ; but the proved similarity of *iso*propyl and β-*n*-octyl halides with regard to mechanism of substitution shows that the behaviour of the *iso*propyl group may be assumed to be typical of that of all purely aliphatic *sec.*-alkyl groups.

(3) *Aryl Groups.*—These behave similarly, except that, because they are highly polarisable, the large electron demand created by the otherwise uncompensated electron transference in the rate-controlling (first) step of mechanism S_N1 calls forth a peculiarly strong electromeric electron-release. Aryl substitutents at the seat of substitution therefore facilitate mechanism S_N1 much more strongly than do alkyl groups. In the series Alk = CH_3, CH_2Ph, $CHPh_2$, CPh_3, the two mechanisms are of nearly comparable importance at the second member (Olivier and Weber, *Rec. trav. chim.*, 1934, **53**, 869, 891) ; whilst at the third, mechanism S_N1 has taken full control (Ward, J., 1927, 2285). The " mixed " aralphyl group Alk = CHMePh has the expected intermediate character between $CHMe_2$ and $CHPh_2$: in aqueous solvents mechanism S_N1 assumes control (Ward, J., 1927, 445), but in less ionising, dry alcoholic solvents the two mechanisms can be observed simultaneously (Hughes, Ingold, and Scott, this vol., p. 1201).

(4) *Carboxyl Groups.*—Groups of the form $\cdot CO_2R$—which include not only carboxylic

ester and carboxylamide groups, but also the undissociated carboxyl groups of free carboxylic acids and the metal-carboxylate groups of undissociated metallic salts—were not discussed by Hughes and Ingold. Being electron attractors, their introduction in such series as Alk = CH_3, $CH_2{\cdot}CO_2R$, $CH(CO_2R)_2$, $C(CO_2R)_3$ and Alk = CH_2Me, $CHMe{\cdot}CO_2R$, $CMe(CO_2R)_2$ will serve more firmly to establish mechanism S_N2, to the exclusion of S_N1; and this will remain true unless and until the cumulative effect of several electron-attracting groups sufficed to reverse the direction of the electron transferences, and thus to remove the reaction from the category of nucleophilic substitutions.* As evidence we may refer to Cowdrey, Hughes, and Ingold's deduction from their kinetic and optical studies (this vol., p. 1208) that halides for which Alk = $CHMe{\cdot}CO_2R$, although "secondary," undergo hydrolysis and alcoholysis by mechanism S_N2, under conditions in which mechanism S_N1 alone would have operated for simple secondary alkyl halides.

(5) *Carboxylate ion Group.*—The ionic group $\cdot\bar{C}O_2$ is of particular interest since, like alkyl groups, it repels electrons: in a series such as Alk = CH_3, $CH_2(\bar{C}O_2)$, $CH(\bar{C}O_2)_2$, $C(\bar{C}O_2)_3$ we may expect a transition from mechanism S_N2 to mechanism S_N1, just as in series involving the progressive accumulation of alkyl groups. In series such as Alk = CH_3, $CH_2{\cdot}\bar{C}O_2$, $CHMe{\cdot}\bar{C}O_2$, $CMe_2{\cdot}\bar{C}O_2$, in which alkyl and carboxylate-ion groups collectively accumulate at the seat of substitution, and in the analogous "mixed" series Alk = CH_3, $CH_2{\cdot}\bar{C}O_2$, $CHPh{\cdot}\bar{C}O_2$, $CPh_2{\cdot}\bar{C}O_2$, we may likewise anticipate mechanistic change from S_N2 to S_N1. As effects arising from the carboxylate-ion group were not treated previously, the available evidence concerning these theoretical expectations will briefly be reviewed.

Reference has already been made to the first member, methyl halide, of each of the above series. The hydrolysis of bromoacetic acid, the anion of which is the second member, has been investigated by Dawson and Dyson (J., 1933, 49, 1133) and Brooke and Dawson (J., 1936, 497). In summarising their results the last-named authors gave a list of ten reactions which might conceivably participate in the elimination of bromide during the aqueous hydrolysis of bromoacetic acid. Of these ten reactions, four were shown to have zero velocity—a fact which is readily understood, because in these four cases the assumed substituting agents are electrophilic and not nucleophilic. The other six reactions had speeds which, calculated as second-order rate constants for 25° (units: 10^{-6}. min.$^{-1}$ g.-mol.$^{-1}$ l.) may be summarised as follows:

	Reagent.	$CH_2(OH){\cdot}CO_2^-$.	$CH_2Br{\cdot}CO_2^-$.	H_2O.
Compound substituted	$CH_2Br{\cdot}CO_2H$	136	72	0·041
	$CH_2Br{\cdot}CO_2^-$	35	19·3	0·059

For convenience we separate the interacting entities into "compounds substituted" and "reagents." The reactions whose speeds are calculated as of bimolecular reactions with water are kinetically of the first order, and might *a priori* be either bimolecular or unimolecular (S_N2 or S_N1); the other reactions are, of course, demonstrably bimolecular (S_N2). Let us for the moment assume that *all* the reactions are bimolecular. Then since the reagents are nucleophilic, the velocities of substitution for *the same compound substituted* should decrease with decreasing basicity of the reagent; and this appears from the figures. Furthermore, the gaps between the speeds for the first two reagents should be small, since the difference of basicity is small, whilst those between the speeds for the second and third reagent should be large, corresponding to the large difference of basicity; this is also shown by the figures. [Acidity increases in the series $CH_2(OH){\cdot}CO_2H < CH_2Br{\cdot}CO_2H \ll H_3O^+$, and basicity decreases analogously in the conjugate bases.] Again, for *the same reagent*, the bromoacetate anion should substitute more slowly than the undissociated bromoacetic acid molecule, because the greater electron density at the seat of substitution in the former should impede the attack of the nucleophilic reagent. The observed differences are in the right direction for the first two reagents, but not for water; for this reagent the reactivity of the bromoacetate ion is relatively too great: and we take this to mean that part of the

* The reaction is then no longer a hydroxylation, or anything analogous, but a reduction.

calculated second-order rate constant for the action of water on the bromoacetate ion does not belong to the bimolecular process (S_N2), but arises from the incursion of the unimolecular reaction (S_N1). As the truly bimolecular rate constant, estimated from the other figures in the table, is only 0·011, whereas the experimental constant is 0·059, we may say that the main mode of hydrolysis of the bromoacetate ion by water is probably the unimolecular process, the speed of which is determined by halogen ionisation (S_N1). It appears therefore that in the example Alk = $CH_2{\cdot}CO_2^-$ a mechanistic transition from S_N2 to S_N1 is in progress, although a very careful investigation such as Dawson's is necessary in order to detect it.

If this be so the unimolecular mechanism should be well developed in the next member, Alk = $CHMe{\cdot}CO_2^-$, of the "mixed" alkyl-carboxylate series; and it certainly is. Senter and Wood showed (J., 1909, **95**, 1827; 1915, **107**, 1070; 1916, **109**, 681) and Cowdrey, Hughes, and Ingold confirmed (*loc. cit.*) that, in the hydrolysis and alcoholysis of the α-bromopropionate ion, unimolecular substitution proceeds at rates comparable to those with which the bimolecular reactions take place in the presence of considerable concentrations of hydroxide or alkoxide ions. The α-bromo-*n*-butyrate ion exhibits qualitatively similar phenomena, and the relative importance of the unimolecular process in hydrolysis is even greater in this case. Senter gives the following values for the rate constants (time units = min.) for aqueous hydrolysis at 52·4° of the anions of the first three α-bromoaliphatic acids:

	$Br{\cdot}CH_2{\cdot}CO_2^-$.	$Br{\cdot}CHMe{\cdot}CO_2^-$.	$Br{\cdot}CHEt{\cdot}CO_2^-$.
First order (10^4k_1)	1	14	26
Second order (10^4k_2)	65	9	8

The α-bromo-β-phenylpropionate ion, $Br{\cdot}CH(CH_2Ph){\cdot}CO_2^-$, also behaves similarly to the α-bromopropionate and α-bromo-*n*-butyrate ions, but the formation of cinnamic acid by a side reaction complicates quantitative study (Senter and Martin, J., 1917, **111**, 44).

The unimolecular mechanism should be still more prominent in the "mixed" aryl-carboxylate example, Alk = $CHPh{\cdot}CO_2^-$, on account of the electromeric effect of the phenyl substituent. The facts are that the unimolecular mechanism exclusively controls the aqueous hydrolysis of α-chloro- and α-bromo-phenylacetate ions (Senter and Tucker, J., 1915, **107**, 908; 1916, **109**, 690).*

(*B*) *Steric Orientation in the Replacement of* ·Hal *by* ·OR.

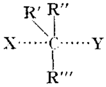
(1) *General Principles.*—Most of the earlier theories of the steric course of substitution, notably those of E. Fischer (*Annalen*, 1911, **381**, 126), Werner (*Ber.*, 1911, **44**, 873; *Annalen*, 1912, **386**, 70), and Pfeiffer (*ibid.*, 1911, **383**, 123), postulate the prior formation of an addition product, in which the entering group attaches itself to the asymmetric carbon atom either on the side of the group to be replaced or on the opposite side; the theories of Gadamer (*J. pr. Chem.*, 1913, **87**, 372) and Meisenheimer (*Annalen*, 1927, **456**, 126) are elaborated forms of the same general view. The idea that addition is not previous to but synchronises with dissociation seems to have been introduced into the theory by Le Bel (*J. Chim. physique*, 1911, **9**, 323), but it was first stated in an acceptable form by G. N. Lewis ("Valence and the Structure of Atoms and Molecules," 1923, p. 113). The remaining alternative, prior dissociation, was assumed by Lowry (*Conseil de Chimie Solvay*, 1925, 130), who suggested that substitution through an intermediate "carbonium" ion might proceed with predominating retention of form; and by Kenyon and Phillips (*Trans. Faraday Soc.*, 1930, **26**, 451; with Lipscomb, J., 1930, 415), who supposed, on the contrary, that it would tend to produce inversion.

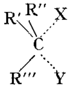
More recent hypotheses concerning the laws which govern the steric orientation of substitution have been advanced by Olson (*J. Chem. Physics*, **1933**, **1**, 418), Meer and

* (*Note added in proof.*) A study of the hydrolysis of bromomalonic acid, methylbromomalonic acid, and the corresponding anions has just been completed by N. A. Taher. The reaction of the bromomalonate ion is unimolecular in dilute solutions of alkali, while that of its methyl derivative remains unimolecular even in moderately concentrated solutions. The velocity relationships, moreover, are in harmony with the predictions made above. The results will be published in conjunction with other similar investigations now in progress.

Polanyi (*Z. physikal. Chem.*, 1932, *B*, **19**, 164), and two of the present authors. Olson and Meer and Polanyi use only the theory of synchronous addition and dissociation. Olson assumes that every substitution in which only one bond is exchanged involves inversion. Meer and Polanyi distinguished between substitutions effected by an anionic reagent (" negative mechanism ") and those in which the attack is by a cation (" positive mechanism "); and they suggested that the former involve inversion whilst the latter do not: some reserve has, however, been expressed with respect to certain examples held to belong to the positive mechanism (Polanyi, " Atomic Reactions," p. 63). Hughes and Ingold (*loc. cit.*) employ the theories of synchronous addition and dissociation and of prior dissociation in conjunction; and they do not make the net charges of the interacting species a primary basis for the classification of substitutions. Treating substitutions as either bimolecular or unimolecular and either nucleophilic or electrophilic (S_N2, S_E2, S_N1, S_E1), they suggested that bimolecular substitutions (S_N2 and S_E2) are invariably accompanied by steric inversion, whilst unimolecular substitutions (S_N1 and S_E1) may involve inversion, racemisation or retention of form, depending on circumstances which have to be considered in detail. Since negative mechanism substitutions are always nucleophilic and bimolecular, there is agreement as to these with Meer and Polanyi's theory; and, of course, with Olson's.

Inversion of configuration is presumed to be the rule for bimolecular substitutions (S_N2 and S_E2) primarily because the transition state (I), which leads to inversion, will have a smaller energy than that (II) which corresponds to retention of stereochemical form:

(I.) 

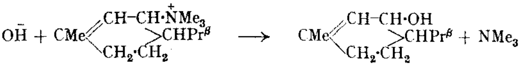
 (II.)

We assess the relative energies of these transition states by application of the exclusion principle; *i.e.*, we consider the conditions which would minimise the repulsive, exchange energy integrals. In either transition state the " split " bond X···C···Y can be described as a state of resonance between the structures X C—Y and X—C Y. In state (I) the charge-cloud of this split bond has a nodal surface which is either a plane (if X = Y) or a very obtuse-angled cone; and the repulsive integrals are minimised if the maxima of electron density due to the bonds CR_3 lie *in this surface. In state (II) the nodal* surface is not a figure of revolution, and it is unlikely that the CR_3-bonds will be able to conform to it; indeed the electron density due to the system $C{<}^{X}_{Y}$ would in general be considerable over the space occupied by the rather sharp-angled pyramid which the CR_3-group must constitute. State (I) will thus correspond to a smaller energy of activation than state (II).

Meer and Polanyi have pointed out that the dipole field in a link such as C—Cl would preferentially direct an anionic reagent such as OH^- to the position leading to inversion; the corresponding statement concerning the transition state is that the repulsion of quasi-ionic charges (δ −)OH···C···Cl(δ −) must be smaller for configuration (I) than for (II). This electrostatic factor must, of course, make a definite contribution to the difference between the theoretical rates of the alternative processes; but we think that the effect arising from the exclusion principle is likely to be more important, and, indeed, in all ordinary cases, determinative. An experimental basis for decision between the two factors can be found, because, although they favour the same stereochemical result in the hydrolysis of alkyl halides, this agreement is fortuitous and does not extend to substitutions generally: in the hydrolysis of 'onium cations, for example, the two factors oppose each other. In the attack of $\bar{O}H$ on $C—\overset{+}{N}R_3$ the electrostatic forces direct the anion to the side of the displaced group; and in the transition state the quasi-ionic charges attract each other, so that the closer they are together the smaller is their mutual electrostatic energy; thus the electrostatic factor favours transition state (II), $C{<}^{OH(\delta -)}_{NR_3(\delta +)}$, and, therefore, substitu-

tion with a retained configuration. On the other hand, the exclusion principle still favours transition state (I), and substitution with an inverted configuration. Hence considerable interest attached to an experimental determination of the steric course of such a reaction.

A determination of this kind has been recorded by Read and Walker (J., 1934, 308; cf. Read, " A Chapter in the Chemistry of Essential Oils," Institute of Chemistry, 1936, p. 21). These authors converted *l*-piperityltrimethylammonium hydroxide into piperitols, and showed that the principal isomeride formed was *d*-*neo*piperitol :



The original piperitylamine belonged to the stable (ordinary) series, and the piperitol to the labile (*neo*-) series; and hence an inversion must have accompanied the substitution. Read's configurations for these compounds, and for two related menthols as reference structures, are as follows :

l-Menthol. *l*-Piperitylamine. *d*-*neo*Piperitol. *d*-*neo*Menthol.

Digressing, we may remark that the same theory requires that in aromatic substitution the reagent attacks from a direction lateral to the plane of the ring : as the attack proceeds, the original substituent becomes deformed until, in the transition state, the atoms lie in two mutually perpendicular planes, as is illustrated with reference to a three-atom nucleophilic, and a four-atom electrophilic substitution :

We have now to consider the unimolecular substitutions (S_N1 and S_E1), in which a carbon cation or anion is formed intermediately. The simplest conditions arise in the absence of any group which, on account of either unsaturation or charge, tends strongly to influence the configuration of the carbon ion. Then for nucleophilic substitutions, if the ion is long-lived, either by reason of an intrinsically small reactivity, or on account of the lack of reactivity of the medium, or of the great dilution of the reagent, the substitution product will be racemised (Hughes and Ingold, *loc. cit.*); this follows because the carbon cation is flat. Frequently, however, the length of life of a carbon cation in a reactive medium is comparable to the period of molecular oscillation or libration of the solute within the enclosing solvent; and in this case the recession of the ion ejected from its former partner will produce a dissymmetric shielding of the latter during the period in which the course of substitution is being determined *; the result will be that substitutions with inversion will outnumber those which retain the original configuration. As an example we may consider the unimolecular hydrolysis (S_N1) of an alkyl halide in a series of solvents ranging from a nearly dry inert solvent to pure water : in the former, racemisation would be most nearly complete, because the great dilution in which water is present affords the ion a comparatively long life; whilst in pure water, inversion would reach its greatest degree of predominance, because under these conditions the ion is short-lived. The theory is the same for electrophilic substitutions if the carbon anion, although its equilibrium configuration is pyramidal, has a plane of symmetry conferred on it by a nuclear resonance effective for the life-time of the ion.† This case, however, is not of much practical importance, since it is hardly possible to produce carbon anions which do not possess stabilising unsaturated substituents.

* In unimolecular substitution the ionisation must nevertheless pass over its energy barrier before the reagent intervenes.

† As nuclear resonance has been demonstrated for ammonia, it could probably occur in the carbon anion with its smaller central nuclear charge, at least if one of the attached groups is a hydrogen atom.

The presence of an unsaturated group, such as phenyl, at the seat of substitution introduces mesomerism, a factor which tends to stabilise and at the same time to flatten the ion (cation or anion) : $\geq C^+$ or $\geq C^-$. The result will be enhanced racemisation, the situation otherwise being exactly as described in the preceding paragraph.

The presence of a charged group of appropriate sign (negative for the organic cation and positive for the anion) tends to stabilise the ion and to preserve a pyramidal configuration; for the " ion " is now a betaine, which has least potential energy in this form. The example which we shall use in illustration later is that of the carboxylic-ion group in a nucleophilic substitution. During the process of ionisation the charged substituent will be oriented away from the eliminated ion; and it will tend to hold the pyramidal configuration thus produced until a new group enters the position from which the old one left : $^-O\!-\!CO\!-\!C^+ \ldots\ldots\ldots\ldots Cl^-$. It may be assumed, as was pointed out to us by Dr. G. W. Wheland, that, contributing to the normal state of the betaine, there should be a canonical structure in which the charges are neutralised at the cost of producing septets, which maintain a tetrahedral character in the orbitals.* The result will be a retention of form, which might be partial or complete. It will be complete if the betaine has sufficient time in which to take up its preferred configuration, but only partial if an external reagent intervenes before this happens.

We can attempt no classification of heterogeneous substitution in general, but in the displacement of halogens from organic halides by means of hydroxyl and similar groups the use of silver oxide and silver salts is of special importance, and therefore merits discussion. In Parts IV and V we showed that the reaction of organic halides with silver oxide was essentially analogous to that with soluble silver salts; and that all such reactions involve a heterogeneous attack by silver ions on the organic halide adsorbed on the surface of an insoluble silver salt (silver halide and/or oxide). We may assume that the adsorption of the halide stretches the carbon-halogen bond (which normally is shorter than the distance between the centres of attraction in the surface of the crystal), and that an adsorbed silver ion takes advantage of this disturbance in order to extract the halogen as an anion. Thus conceived, the substitution process depends on an assisted, heterogeneous ionisation; and the final step must involve the heterogeneous reaction of the carbon cation with an adsorbed, nucleophilic solvent or solute molecule. The general resemblance of the heterogeneous process to homogeneous, unimolecular hydrolysis (S_N1) is obvious, and we may accordingly expect to find certain phenomenological similarities, two of which may be mentioned.

The first relates to the influence of structure on reaction rate. It is evident that if both the S_N1-reaction and the silver-ion reaction depend on a preliminary ionic fission of the halide, the latter reaction, like the former, should be facilitated by access of electrons to the seat of substitution. For instance, the electron-repelling substituent $\cdot CO_2^-$ should accelerate reaction, whilst the electron-attracting groups $\cdot CO_2H$ and $\cdot CO_2Me$ should retard it. The expected effect for both these reactions is the opposite of that normal for the S_N2-reaction, which is facilitated by the withdrawal of electrons from the seat of substitution. The evidence on these matters is contained in Parts III and V. First, with regard to the silver reaction, we show that the hydroxylation of α-bromopropionic acid with aqueous silver nitrate proceeds mainly through the anion of the bromo-acid even in the presence of a $1N$-concentration of hydrogen ions : this means that the specific rate of substitution of the bromo-anion must be more than 1000 times greater than the rate for the undissociated acid. Secondly, for the homogeneous unimolecular reaction S_N1, we find that the α-bromopropionate ion is methoxylated at 64° in methyl alcohol by this reaction about 20 times faster than methyl α-bromopropionate is methoxylated at 100° by an S_N2-reaction which itself is fast enough completely to mask the S_N1-reaction : at equal temperatures, therefore, the S_N1-reaction of the anion must be considerably more than 1000 times faster than that of the ester. Thirdly, for contrast, we may take the S_N2-methoxylations of the same substances : it can easily be computed from the recorded data that, at like temperatures, the reaction of the anion must be of the order of 100 times slower than that of the ester.

* For reasons mentioned later (p. 1264) we are not prepared to assume the formation of an α-lactone.

Thus, with respect to the effect of structure on rate, the silver-ion reaction resembles the S_N1- rather than the S_N2-process—as it should according to our theory of the mechanism.

The other type of correspondence to be expected between the silver-ion reaction and the homogeneous unimolecular process is concerned with the spatial orientation of substitution. The physical conditions in a surface being different from those obtaining in homogeneous reactions, we can make no quantitative comparisons, in regard, for instance, to the amount of racemisation to be anticipated; but a qualitative similarity should hold. For example, the silver-ion reaction with alkyl halides should exhibit inversion of form with accompanying racemisation; that with aralphyl halides inversion with more extensive racemisation; and that with α-halogeno-carboxylate ions retention of form with racemisation. The evidence is considered in the next sub-section.

Intermolecular rearrangements are difficult to classify, since they have analogies with bimolecular and unimolecular substitutions. It is obvious, however, that we may expect retention of configuration when the point in the rearranging chain at which it is able to recombine is not sufficiently far removed from the point at which it breaks loose to permit the formation of a transition state of type I (with X and Y connected by a chain): a transition state of form II (but cyclic) is then the only possibility.

(2) *Alphyl and Aralphyl Halides* (*Orientation Rules*).—There seems to be no previous record of any investigation of steric orientation in the homogeneous hydrolysis of an alkyl halide under any conditions, and certainly none for hydrolysis under conditions specified with respect to kinetics. We may, however, take β-*n*-octyl bromide as a typical halide containing, besides the halogen, only neutral, saturated substituents at the seat of substitution. In Part I we showed that bimolecular hydrolysis and alcoholysis (S_N2) proceeds with inversion of configuration and a practically quantitative preservation of the optical rotatory power; whilst unimolecular hydrolysis and alcoholysis (S_N1) takes place with a predominating inversion but extensive racemisation. These results accord well with the theory set forth in the preceding sub-section: we may reasonably draw two conclusions. The first is that in all homogeneous substitutions of ·Hal by ·OR in alkyl halides, no matter whether the mechanism is S_N2 or S_N1, the predominating orientation will be inversion: this principle seems so definite that we should be able to use it for the purpose of diagnosing the relationship of molecular configuration to sign of rotation. The second conclusion is that the absence of racemisation in mechanism S_N2, and the extensive racemisation characteristic of mechanism S_N1, afford a basis for an auxiliary diagnosis of mechanism from optical results alone.

Concerning the effect of the presence of a neutral, unsaturated substituent at the seat of substitution, we have again to rely on our own data; but α-phenylethyl chloride may be taken as typical for this case. In Part II we showed that, although the bimolecular hydrolysis of this halide could not be realised, bimolecular alcoholysis (S_N2) proceeded with inversion and a high retention of rotatory power; and that unimolecular hydrolysis and alcoholysis (S_N1) took place with predominating inversion, but with extensive racemisation, which further increased when the water in the medium was diluted with an inert solvent (acetone). These results are qualitatively similar to those obtained for the purely aliphatic halide, and hence we may conclude that aralphyl halides will conform to the generalisations mentioned in the previous paragraph: substitution by either mechanism will give inversion and the two mechanisms will be distinguishable through the racemisation which characterises one of them. The effect of the unsaturated (aryl) substituent is confined to increasing the relative importance of the unimolecular mechanism, and to increasing the amount of racemisation which accompanies its operation: both these effects are expected from our theory (sub-sections A3 and B1). It is also consistent with theory that racemisation in substitution by the unimolecular mechanism is increased when we prolong the life of the organic ion by diluting the reactive with an unreactive solvent (*e.g.*, water with acetone).

As an example of the use of our diagnostic rules, reference may be made to the observation (Part II) that (+)α-phenylethyl chloride, on solution in liquid ammonia, gives (−)α-phenylethylamine. This is obviously a nucleophilic substitution, although it is not a replacement of ·Hal by ·OR; but the same rules will surely apply to replacements of ·Hal by $\cdot NR_2$. No kinetic investigation was carried out, but it is unnecessary to consider whether

the mechanism of the reaction is S_N2 *or* S_N1 *in order to decide its steric course: the mechanism must be one or the other, and hence the predominating orientation must be inversion; therefore the (+)chloride and (+)amine are configuratively related.*

Inasmuch as the diagnostic rules follow from our theoretical considerations, as well as agreeing with the experimental evidence, we may regard stereochemical classifications reached in the manner now illustrated as having a basis which is independent of the rather elaborate arguments employed in Parts I and II. We can directly use the orientation rule in order to establish configurational analogy with each of the following sets of optically active compounds:

(1) β-n-*Octyl Derivatives*:—(+)Chloride, (+)Bromide, (+)Alcohol, (+)Ethyl ether, (+)Acetate.
(2) α-*Phenylethyl Derivatives*:—(+)Chloride, (+)Bromide, (+)Alcohol, (+)Methyl ether, (+)Ethyl ether, (+)Amine.

Most of the substitutions utilised in making these stereochemical classifications are recorded in Parts I and II, but the direct transformations of β-*n*-octyl halides into the acetate were described by Pickard and Kenyon (J., 1911, **99**, 45). These authors first correctly diagnosed the stereochemical relationship between β-*n*-octyl bromide and the alcohol by comparison of the rotatory dispersion diagrams (*loc. cit.*): the contrary conclusions reached later by Levene and Mikeska are based on quite untenable arguments (*J. Biol. Chem.*, 1924, **59**, 45).

We have still to consider the substitution undergone by alkyl and aralphyl halides under the influence of silver oxide or silver salts in the presence of hydroxylic solvents. In Part IV we showed that the hydroxylation and ethoxylation of β-*n*-octyl bromide by means of silver oxide suspended in aqueous alcohol proceeded with predominating inversion of configuration and considerable accompanying racemisation; and that a like statement is true for the substitutions which were promoted by the soluble silver salts, silver nitrate and silver acetate, in a similar solvent. We showed also that predominating inversion with particularly extensive racemisation characterised the hydrolysis of α-phenylethyl chloride in aqueous solvents. These are the effects to be expected on our view (sub-section B,1) of the reaction with silver salts as a heterogeneous analogue of unimolecular hydrolysis (mechanism S_N1). It would seem that we can safely generalise, postulating a predominating inversion of configuration in all reactions of alkyl or aralphyl halides with silver salts.

(3) *Halogeno-acids and their Esters and Salts* (*Orientation Rules*).—There are no previously recorded observations from which we could with any confidence deduce empirically the rules governing steric orientation in the homogeneous hydrolysis or alcoholysis of halides containing a carboxyl group in its various forms as a substituent at the seat of substitution. We consider, however, that α-bromopropionic acid, its ester and anion are essentially typical of the structures which we wish to treat, and that accordingly generalisations based on the results of Part III are justified.

We may first consider non-ionised forms of the carboxyl substituent. In Part III we investigated two such forms, *viz.*, the ester group $\cdot CO_2Me$, and the undissociated carboxyl group $\cdot CO_2H$ (which was maintained in a non-ionised state by the addition of extraneous hydroxonium ions). The methyl alcoholysis of methyl α-bromopropionate was investigated under alkaline conditions, for which it was possible to prove kinetically that the mechanism was bimolecular, S_N2; and the stereochemical result was inversion without significant racemisation. The methyl alcoholysis of the same ester was also investigated under acid conditions, in which a secondary alkyl halide would have undergone substitution by the unimolecular mechanism S_N1; but, although no strict demonstration of the nature of the mechanism was possible in the case of this ester, the extreme slowness of reaction suggested that the mechanism was bimolecular, S_N2; and the optical result was inversion without appreciable racemisation. Then the acid hydrolysis of undissociated α-bromopropionic acid was examined; again the mechanism could not be demonstrated from the kinetics, but the slow rate suggested that it was bimolecular, S_N2—and again the optical result was inversion with no definitely detectable racemisation. It is, of course, quite in agreement with theory (sub-section A, 4) that non-ionised forms of the carboxyl group, which are strong attractors

of electrons, should suppress substitution by mechanism S_N1; and the uniformity of the optical result confirms our assumption that all the above-mentioned substitutions proceed by mechanism S_N2. It would appear to be impossible to realise mechanism S_N1 in the hydrolysis or alcoholysis of a halide (ammonolysis remains to be investigated), in which, besides a non-ionic carboxyl form such as $\cdot CO\cdot OH$, $\cdot CO\cdot OR$, $\cdot CO\cdot NH_2$, $\cdot CO\cdot NR_2$, etc., only one alkyl group and a hydrogen atom are attached at the seat of substitution. For substitution by mechanism S_N2 the theoretical considerations of sub-section B,1 require just what we find, *viz.*, inversion without substantial racemisation.

In the presence of two alkyl groups or an aryl group, in addition to a non-ionised form of the carboxyl group, *e.g.*, in $CMePhCl\cdot CO_2Me$, it probably would be possible to effect hydrolysis or alcoholysis by mechanism S_N1. Then, since the carbon ion is flat in its equilibrium configuration and intrinsically unstable, we may expect a predominating inversion accompanied by considerable racemisation, which will be further increased by dilution of the hydroxylic with a non-hydroxylic solvent. These theoretical predictions cannot be tested by any of the experimental results we have obtained hitherto, but the planned extensions of this research include the study of examples which should provide the necessary check.

Next we have to consider the carboxylate-ion substituent: this repels electrons and therefore facilitates substitution by mechanism S_N1 (sub-section A, 5). In Part III we describe an investigation of both the methyl alcoholysis and the hydrolysis of the α-bromopropionate ion. Methyl alcoholysis was found to occur in general by both the bimolecular and the unimolecular mechanism, but by suitably choosing the concentrations of the reactants the separate mechanisms, S_N2 and S_N1, could be isolated; and methoxylation by mechanism S_N2 took place with inversion of configuration and with no appreciable racemisation; whilst by mechanism S_N1 it proceeded with a practically quantitative retention of the original stereochemical form. Similar results were obtained for hydrolysis.

Summarising, we may say that in the presence of the carboxylate-ion group, substitution by the bimolecular mechanism, S_N2, leads, as usual, to a substantially complete inversion of configuration. This accords with the requirements of theory (sub-section B, 1). On the other hand, reaction by the unimolecular mechanism, S_N1, produces essentially a retained configuration. This is also in conformity with the theory, which points out that the most stable configuration of the intermediate carbon cation is now, not planar, but pyramidal (*loc. cit.*).

The steric orientation of substitution undergone by α-halogeno-acids and their derivatives under the influence of silver oxide or silver salts in the presence of hydroxylic solvents was considered in Part V. The data relate to derivatives of α-bromopropionic acid, and once again a clear distinction was found between those compounds which contain a formally neutral modification of the carboxyl group in attachment to the seat of substitution, and the α-bromopropionate ion which has a charged carboxyl substituent.

The former case is illustrated by the hydroxylation of an amide by means of silver carbonate and water, and the methoxylation of an ester by silver nitrate in methyl alcohol. In each case the stereochemical outcome was a predominating inversion with accompanying partial racemisation. As is pointed out above, a homogeneous unimolecular substitution (S_N1) of the halogen atom in compounds having neutral modifications of the carboxyl group attached to the asymmetric centre has probably not yet been realised; but it is theoretically expected to lead to inversion with racemisation. Furthermore, our view that the reaction of halides with silver salts is a heterogeneous analogue of unimolecular substitution implies qualitative similarity of steric orientation. Thus the experimental results seem intelligible, and it can probably be accepted as general that the reactions of α-halogeno-esters and -amides with silver salts will proceed with predominating inversion.

The hydrolysis of the α-bromopropionate ion was investigated with silver oxide, and with silver nitrate, in the presence of aqueous solvents. Under all conditions substitution proceeded with a predominating retention of form and some accompanying racemisation. The retention of form constitutes qualitative analogy with the homogeneous unimolecular substitution (S_N1) of the anion. The racemisation, considerable with silver oxide, was small with silver nitrate; it is small at most in the unimolecular substitution (S_N1). On

the whole, therefore, the expected qualitative analogy between the silver reactions and the S_N1 process seems well supported; and we may accordingly assume that a predominating retention of configuration will be the normal result of attack by silver ions in a hydroxylic solvent on the anions of α-halogeno-acids (cf. pp. 1243, 1263).

(4) *Halogeno-acids and their Salts* (*Review of Literature*).—There has been so little previous work on the steric course of the hydrolysis of alkyl halides that no further reference to these compounds is necessary. In the field of the halogeno-acids, however, observations have been recorded, which, although unco-ordinated, and often insufficiently precise in the specification of conditions, are numerous enough to justify discussion. In most examples some at least of the recorded observations can be used in conjunction with our orientation rules in order to establish the stereochemical connexion between factors and products.

The example which from a structural point of view most closely resembles our simple one of α-bromopropionic acid is α-bromo-β-phenylpropionic acid: the groups which influence the substitution are the same except that benzyl replaces methyl, and the effect of this change will be merely to increase slightly the tendency towards unimolecular substitution. McKenzie, Wren, and Barrow hydrolysed α-bromo-β-phenylpropionic acid by means of aqueous sodium hydroxide, the maximal alkalinity of which was 0·06*N*, by means of water in the presence of calcium carbonate, by water alone, by water acting on the silver salt of the acid, and by water and excess of silver oxide acting on the silver salt (J., 1910, **97**, 1355; 1911, **99**, 1921). No kinetic study was made, but we can be sure that under all these conditions the dominant mechanism will be either the homogeneous unimolecular mechanism S_N1, or the heterogeneous modification of this already considered, the entity substituted being the anion: the stereochemical outcome should therefore in all cases be a retention of configuration. In all five experiments McKenzie, Wren, and Barrow obtained an α-hydroxy-β-phenylpropionic acid with a retained sign of rotation. It is therefore certain that the bromo- and hydroxy-acids which have like signs of rotation have like configurations. The same authors hydrolysed α-chloro-β-phenylpropionic acid by means of water and calcium carbonate, and obtained a hydroxy-acid with a retained sign of rotation. This proves that chloro- and hydroxy-acids with like signs of rotation also have corresponding configurations.

In the halogenophenylacetic acids the aryl substituent creates an increased tendency to unimolecular substitution (S_N1); and it is known experimentally that the homogeneous *hydroxylation of the anions of these halogeno-acids pursues a unimolecular course practically* exclusively (sub-section A, 5). The steric course of this reaction must be determined jointly by the carboxylate-ion group and by the phenyl group: the former causes retention of configuration and the latter racemisation, so that the joint effect of the groups should be to produce a predominating retention of form accompanying racemisation.

McKenzie and Clough treated α-chlorophenylacetic acid with water, and its sodium salt with water, aqueous sodium carbonate, and aqueous sodium hydroxide; in each case the mandelic acid which was produced retained the original sign of rotation but was largely racemised (J., 1908, **93**, 811; 1909, **95**, 777). Under all the conditions mentioned the reaction must have consisted essentially in the unimolecular hydrolysis of the anion of the chloro-acid: this is true, on the one hand, for the experiment involving sodium hydroxide because of the strong joint effect of the phenyl and carboxylate-ion groups in favouring unimolecular hydrolysis; and, on the other, for the experiment with the free chloro-acid, because, in spite of the low concentration of the anion, its great reactivity will ensure that hydrolysis goes by that route. Comparing the expected steric orientation of the unimolecular reaction of the anion with the observed effect of substitution on the sign of rotation in the experiments mentioned, we see that chloro- and hydroxy-phenylacetic acids with like signs of rotation are configuratively similar. We can include α-methoxyphenylacetic acid in the same statement on the basis of homogeneous methoxylations of the sodium salt of the chloro-acid, in which also the sign of rotation was retained.

α-Bromophenylacetic acid was investigated by McKenzie and Walker (J., 1915, **107**, 1685; *cf.* Ward, J., 1926, 1184) who brought about hydroxylation by the action of water on the acid, and by water and by aqueous sodium hydroxide acting on the sodium salt. The products of these experiments were almost inactive, although in the first case small

rotations, some with an inverted sign, were observed. Small rotations with a retained sign were obtained when the reaction was complete as judged by the elimination of halogen, although after considerably longer periods inversion of sign occurred. This observation makes it evident that the inversions are due to the interaction of two molecules of the acid (or anion) to form esters (or lactide) which are rapidly produced with, and slowly hydrolysed without, inversion. We assume inversion in the formation of such esters, because the reaction must be essentially bimolecular; and retention of form in their hydrolysis, because the fission would not exchange a bond attached to the asymmetric carbon atom (cf. p. 1265). The methoxylation of α-bromophenylacetic acid, effected by treatment of the sodium salt with methyl alcohol, proceeded with retention of the sign of rotation. The conclusion is that configuratively related bromo-, hydroxy-, and methoxy-phenylacetic acids have like signs of rotation.

McKenzie and his collaborators effected the hydroxylation and methoxylation of chloro- and bromo-phenylacetic acid by the agency of silver salts in the presence of water or methyl alcohol: the hydroxy- or methoxy-acid produced had in each case an inverted sign of rotation. This happened, for instance, when, according to the description given, the silver salt of the halogeno-acid was prepared and subsequently decomposed by means of water or methyl alcohol. The stereochemical result seems anomalous, because, if reaction is determined essentially by an attack of silver ions on the anion of the halogeno-acid, there should be a predominating retention of form, and therefore a retained sign of rotation. Reconciliation arises through our observation, which will be published later, that the preparation of the silver salts of these highly reactive halides is not the simple process imagined, but involves the production of esters by the interaction of two organic molecules; these esters are eventually hydrolysed or alcoholysed, and the over-all result is inversion for the reasons indicated above.

Rather similar conditions apply to α-chloro-α-phenylpropionic acid, which was examined by McKenzie and Clough (J., 1910, **97**, 1016, 2564). Homogeneous hydrolysis, which takes place very rapidly both in acid and in alkaline solution, and is surely unimolecular, leads to a wholly racemised product. Hydrolysis by means of silver salts takes a course similar to that outlined in the preceding paragraph, and leads eventually to an α-hydroxy-acid with an inverted sign of rotation, which we may presume to correspond to an inverted configuration.

The only monobasic aliphatic β-halogeno-acid which has been studied in connexion with the steric course of hydrolysis is β-chlorobutyric acid. Fischer and Scheibler hydrolysed the methyl ester and the free acid with aqueous hydrochloric acid, and the silver salt with silver oxide and water (*Ber.*, 1909, **42**, 1219); in all these experiments they obtained a partly racemised β-hydroxybutyric acid with an inverted sign of rotation. The type to which the first of these experiments, and, more doubtfully, the second and third may be expected to conform is the S_N1 hydrolysis, or its heterogeneous analogue, of a secondary alkyl halide; we expect, therefore, partial racemisation with a predominating inversion of configuration. The conclusion may be drawn that a β-chloro- and a β-hydroxy-butyric acid with like signs of rotation are configuratively similar.

The β-halogeno-β-phenylpropionic acids are in like case, except that the presence of the aryl substituent at the seat of substitution will ensure the domination of unimolecular hydrolysis (S_N1) even in alkaline solution. The hydrolysis of β-chloro- and β-bromo-β-phenylpropionic acid has been investigated by McKenzie and Humphries (J., 1910, **97**, 121), McKenzie and Barrow (J., 1911, **99**, 1921), and Fischer and Scheibler (*Annalen*, 1911, **383**, 337). The bromo-acid on hydrolysis, either with water alone or with aqueous sodium carbonate, gave a β-hydroxy-β-phenylpropionic acid with an inverted sign of rotation, and a similar result was obtained on hydrolysis with silver oxide and water. The chloro-acid on hydrolysis by means of water alone behaved like the bromo-acid. We may conclude that the chloro-, bromo- and hydroxy-acids which have like signs of rotations have corresponding configurations.

The halogenosuccinic acids figured in Walden's original discovery of optical inversion (*Ber.*, 1896, **29**, 133; 1897, **30**, 3146; 1899, **32**, 1833, 1855), and their hydrolysis has since been investigated by Holmberg (*J. pr. Chem.*, 1913, **87**, 456; **88**, 553; *Arkiv Kemi Min.*

Geol., 1916, **6**, No. 8, 1; 1917, **6**, No. 23, 33; *Ber.*, 1927, **60**, 2194), Bancroft and Davis (*J. Physical Chem.*, 1931, **35**, 1253) and Rördam (J., 1932, 2931; *Ber.*, 1934, **67**, 1595). The presence of an α- and a β-carboxyl group leads to considerable complication, and it is not possible on the basis of the particulars given to interpret unequivocally every detail of the reported experiments. However, the main features are outlined below. Some of the results quoted have been obtained with one, and some with several of the halogenosuccinic acids (chloro-, bromo- and iodo-); but, as there is no evidence of any significant difference of behaviour between them, we shall discuss them collectively.

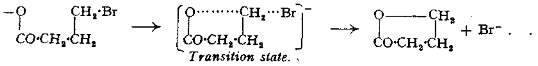
Hydrolysis by means of an excess of a soluble metallic hydroxide is kinetically of the second order and leads to a malic acid with an inverted sign of rotation. This tells us that the mechanism is bimolecular (S_N2), and that, since such a reaction must invert configuration, those halogenosuccinic and malic acids which have rotations of like sign have similar configurations.

The hydrolysis of the sodium salt in water follows no simple kinetic order, and gives a malic acid with a retained sign of rotation, and therefore a retained configuration. The unimolecular mechanism (S_N1) would produce this stereochemical result; and a simple kinetic order is not to be expected, since under the conditions chosen the liberated hydrogen bromide is continually causing replacement of the halogenosuccinate ion by the much less reactive free acid. (In our experiments on α-bromopropionic acid, we kept an extra equivalent of alkali in the solution in order to avoid this complication.) On the other hand, the observations mentioned below show that there is also another route through which a malic acid with a retained configuration could be produced.

When a halogenosuccinic acid is treated with one equivalent of a soluble silver salt a lactonic acid is formed, which has an inverted sign of rotation. There has been much discussion, first, as to whether this malolactonic acid is an α- or a β-lactone, and secondly, as to whether it is formed with retention or inversion of configuration. In our view a definite answer can be given to both these questions. The substance is a β-lactone, because its production is peculiar to the halogenosuccinic acids, and has not been paralleled for any of the numerous monobasic α-halogeno-acids which have been investigated, some under the definite preconception that an analogue of malolactonic acid would be produced; and furthermore because β-lactones are common substances, particularly well known in the succinic acid series, whereas unpolymerised α-lactones are quite unknown. Malolactonic acid is formed with an inversion of configuration because the most probable reaction mechanism is an "intramolecular variety" of the bimolecular mechanism (S_N2); * and also because a halogenosuccinic acid and the lactonic acid derived from it have separately been converted, both by obviously bimolecular substitutions, into enantiomeric xanthates. It follows that a β-malolactonic acid and a malic acid with rotations of the same sign have like configurations.

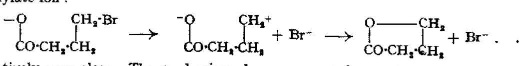
β-Malolactonic acid undergoes hydrolysis to malic acid by three distinct mechanisms; in concentrated or dilute alkaline solution reaction is rapid and preserves the configuration; in dilute acid it is slow and inverts configuration; in more concentrated acid it is compara-

* We mean that the carboxylate-ion group attacks the halogen-bearing carbon atom, and we take the same view with regard to the first-order lactonisation of the γ-bromobutyrate ion (Caldin and Wolfenden, J., 1936, 1239):



(S_N2)

Analogy suggests that the alternative of ionic fission of the carbon–halogen bond before intervention of the carboxylate ion:



(S_N1)

would be relatively very slow. The mechanisms here represented are "intramolecular varieties" of S_N2 and S_N1 respectively. They are kinetically indistinguishable; but in some cases, although not in this, a stereochemical criterion for their distinction could be devised.

tively slow and retains configuration. The first and third of these reactions correspond to the ordinary alkaline and acid hydrolyses of esters. It has been shown by methods based on the use of optical activity (Holmberg, *Ber.*, 1912, **45**, 2997), the principle of mesomerism (Ingold and Ingold, J., 1932, 756), and the isotopes of oxygen (Polanyi and Szabo, *Trans. Faraday Soc.*, 1934, **30**, 508) that, when a carboxylic ester is hydrolysed by acids or alkali, fission takes place between the singly bonded oxygen atom and the carbonyl group; therefore these mechanisms applied to β-malolactonic acid cannot produce inversion. However, in the absence of any alkali, and of sufficient acid to give adequate speed to the intrinsically slow process of acid saponification, it becomes possible to observe a bimolecular displacement of the acyloxy-group by water molecules, a process which involves inversion.

Malic acid with a retained configuration is produced when water is allowed to act not only, as already mentioned, on the sodium salts of halogenosuccinic acids, but also on the silver salts, and on the free acids. In any of these cases it could be supposed, as indeed it has been, that malolactonic acid is first formed with one inversion and then hydrolysed with another. To what extent this double process does in fact contribute to the observed optical results cannot be decided from the existing kinetic data. When silver halogenosuccinates are treated with silver oxide, a much racemised malic acid is formed with an inverted configuration: the most probable cause seems to be the incursion of the alkaline hydrolysis of the lactonic acid. But independently of these details, which only a careful kinetic investigation can clear up, we have a sufficient number of transformations to which the orientation rules can safely be applied in order definitely to establish configurative relationships between the three halogenosuccinic acids, malolactonic acid, and malic acid.

There is similar cause for complicated behaviour in α-chloroglutaric acid, although the hydrolysis of this substance has not been investigated in such detail as has that of bromosuccinic acid. Using aqueous sodium hydroxide, water alone, and silver oxide and water, Fischer and Moreschi hydrolysed α-chloroglutaric acid to α-hydroxyglutaric acid, which in each case had a changed sign of rotation (*Ber.*, 1912, **45**, 2447). Under the first-named conditions the reaction would be essentially of the S_N2 type, and would involve inversion. The reactions with water alone, and with silver oxide and water, probably proceed by way of the very easily formed γ-lactonic acid, which is here produced with inversion and hydrolysed, in the manner of an ordinary carboxylic ester, without inversion. We may conclude that those chloro- and hydroxy-acids which have like signs of rotation have like configurations.

There is one halogeno-acid, *viz.*, α-bromo*iso*valeric acid, which has been hydrolysed to an optically active hydroxy-acid, whose stereochemical relationship to the bromo-acid we are nevertheless unable to assign. The conditions of the recorded experiments (Fischer and Scheibler, *Ber.*, 1908, **41**, 2891) are so similar to those for which we would expect a change of mechanism that we should require to carry out kinetic measurements before venturing to interpret the optical observations.

Our discussion establishes that the following sets of compounds have corresponding configurations * :—

(1) *α-Substituted Propionic Acids:* (+)Chloro-, (+)Bromo-, (+)Iodo-, (+)Methoxy-propionic acid, (−)Lactic acid.
(2) *α-Substituted β-Phenylpropionic Acids:* (+)Chloro-, (+)Bromo-, (+)Hydroxy-β-phenylpropionic acid.
(3) *α-Substituted Phenylacetic Acids:* (+)Chloro-, (+)Bromo-, (+)Methoxy-phenylacetic acid, (+)Mandelic acid.
(4) *α-Substituted α-Phenylpropionic Acids:* (+)Chloro-, (+)Hydroxy-α-phenylpropionic acid.
(5) *β-Substituted* n-*Butyric Acids:* (+)Chloro-, (+)Hydroxy-*n*-butyric acid.
(6) *β-Substituted β-Phenylpropionic Acids:* (+)Chloro-, (+)Bromo-, (+)Hydroxy-β-phenylpropionic acid.

* Following common usage, we employ (+) and (−) to signify sign of rotation. Lævorotatory lactic acid gives dextrorotatory salts, *i.e.*, (−)lactic acid and (+)lactate ion belong to the same stereochemical class (*d*-series).

(7) *Substituted Succinic Acids :* (+)Chloro-, (+)Bromo-, (+)Iodo-succinic acid, (+)β-Malolactonic acid, (+)Malic acid.
(8) α-*Substituted Glutaric Acids :* (+)Chloro-, (+)Hydroxy-glutaric acid.

This list agrees well with Frankland's (J., 1913, **103**, 725), but poorly with Clough's (J., 1918, **113**, 526). Previous authors have based their assignments largely on a statistical survey of the recorded optical effects of particular reagents, and Frankland seems to have made a circumspect use of the rule that, when in a large majority of examples a particular reagent causes retention or inversion of the sign of rotation, then the action of that reagent is characterised by retention or inversion of configuration as the case may be. This may be a good general guide, *but it takes insufficient account of mechanism :* we have seen that the same reagent may behave in stereochemically different ways towards different compounds, and even towards the same compound under different conditions. Our assignment, on the other hand, is based wholly on a consideration of mechanism, and does not make use of any view about the statistical probability that stereochemically analogous structures will have like signs of rotation.

(C) *Steric Orientation in the Replacement of* ·OR *by* ·Hal.

(1) *Replacements by Means of Halides of Phosphorus and Sulphur.*—The configurational relationships established in section (B) enable us to make definite statements concerning the stereochemical behaviour of those reagents which, acting on the hydroxy-compounds, restore a halogen atom. In this sub-section we shall consider replacements effected by means of phosphorus halides and oxyhalides and thionyl halides, either in the absence or in the presence of a tertiary base such as pyridine. The following table contains a list of halogenations the steric course of which can unequivocally be specified on the basis of the conclusions of section (B).

(a) *Substitutions with Inversion of Configuration : Reagents and Hydroxy-compounds.*

Phosphorous Trichloride.—β-*n*-Octyl alcohol (22), α-Phenylethyl alcohol (11), Ethyl β-hydroxy-β-phenylpropionate (24).

Phosphorus Trichloride and Pyridine.—α-Phenylethyl alcohol (21), Ethyl β-hydroxy-β-phenylpropionate (24).

Phosphorus Oxychloride.—β-*n*-Octyl alcohol (22), α-Phenylethyl alcohol (21).

Phosphorus Oxychloride and Pyridine.—α-Phenylethyl alcohol (21), Methyl mandelate (19).

Phosphorus Pentachloride.—β-*n*-Octyl alcohol (22), α-Phenylethyl alcohol (15, 21), Lactic acid (3, 4), Ethyl lactate (5), Malic acid (1), Methyl malate (2), Ethyl malate (2), β-Hydroxy-*n*-butyric acid (8, 12), Methyl β-hydroxy-*n*-butyrate (8, 12), β-Hydroxy-β-phenylpropionic acid (13), Ethyl β-hydroxy-β-phenylpropionate (24), α-Hydroxy-β-phenylpropionic acid (10), Mandelic acid (6, 7), Methyl mandelate (6, 7), Menthyl mandelate (23), α-Hydroxy-α-phenylpropionic acid (11), Ethyl α-hydroxy-α-phenylpropionate (11).

Phosphorus Pentachloride and Pyridine.—β-*n*-Octyl alcohol (22), α-Phenylethyl alcohol (21), Ethyl lactate (25).

Phosphorus Tribromide.—Ethyl β-hydroxy-β-phenylpropionate (24).

Phosphorus Tribromide and Pyridine.—Ethyl β-hydroxy-β-phenylpropionate (24).

Phosphorus Pentabromide.—α-Phenylethyl alcohol (14), Lactic acid (4), Methyl lactate (4), Ethyl lactate (3, 6), Methyl malate (2), Ethyl malate (2), β-Hydroxy-β-phenylpropionic acid (9), Methyl β-hydroxy-β-phenylpropionate (9), Mandelic acid (6), Methyl mandelate (6).

Phosphorus Pentabromide and Pyridine.—Ethyl lactate (25).

Thionyl Chloride.—β-*n*-Octyl alcohol (17), Lactic acid (15), Ethyl lactate (15, 25), Malic acid (13), Ethyl malate (13), Ethyl α-hydroxy-β-phenylpropionate (13).

Thionyl Chloride and Pyridine.—β-*n*-Octyl alcohol (18), α-Phenylethyl alcohol (21), Ethyl lactate (16, 25), Ethyl mandelate (20), Ethyl β-hydroxy-β-phenylpropionate (24).

Thionyl Bromide and Pyridine.—β-*n*-Octyl alcohol (18).

(b) *Substitutions with Retention of Configuration: Reagents and Hydroxy-compounds.*

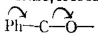
Thionyl Chloride.—α-Phenylethyl alcohol (15), β-Hydroxy-β-phenylpropionic acid (13), Ethyl β-hydroxy-β-phenylpropionate (24), Mandelic acid (13), Methyl mandelate (13), Ethyl mandelate (13), Menthyl mandelate (23), α-Hydroxy-α-phenylpropionic acid (11), Ethyl α-hydroxy-α-phenylpropionate (11).

References.—(1) Walden, *Ber.*, 1893, **26**, 215. (2) *Idem*, *Ber.*, 1895, **28**, 1289. (3) *Idem*, *ibid.*, p. 1293. (4) Walker, J., 1895, **67**, 918. (5) Purdie and Williamson, J., 1896, **69**, 820. (6) Walden, *J. Russ. Phys. Chem. Soc.*, 1898, **30**, 669. (7) McKenzie and Clough, J., 1908, **93**, 811. (8) Fischer and Scheibler, *Ber.*, 1909, **42**, 1219. (9) McKenzie and Humphries, J., 1910, **97**, 121. (10) McKenzie and Wren, *ibid.*, p. 1356. (11) McKenzie and Clough, *ibid.*, pp. 1016, 2564. (12) Fischer and Scheibler, *Annalen*, 1911, **383**, 339. (13) McKenzie and Barrow, J., 1911, **99**, 1910. (14) Holmberg, *Ber.*, 1912, **45**, 997. (15) McKenzie and Clough J., 1913, **103**, 687. (16) Frankland and Garner, J., 1914, **105**, 1101. (17) Levene and Mikeska, *J. Biol. Chem.*, 1924, **59**, 45. (18) McKenzie and Tudhope, *J. Biol. Chem.*, 1924, **62**, 551. (19) Wagner-Jauregg, *Helv. Chim. Acta*, 1929, **12**, 61. (20) Kenyon, Lipscombe, and Phillips, J., 1930, 415. (21) Kenyon, Phillips, and Taylor, J., 1931, 382. (22) Houssa and Phillips, J., 1932, 108. (23) McKenzie and Smith, J., 1923, **123**, 1962. (24) Kenyon, Phillips, and Shutt, J., 1935, 1663. (25) Gerrard, Kenyon, and Phillips, this vol., p. 153.

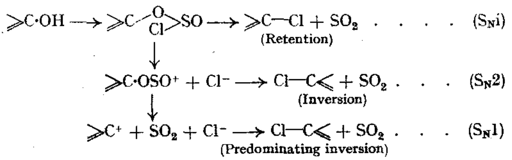
From these steric orientations we might conclude, with Frankland, that the halides of phosphorus always bring about inversion of configuration, and that thionyl chloride does so unless a phenyl group is attached to the seat of substitution; as Kenyon and Phillips first noticed, this peculiarity of the phenyl substitutent disappears if the reaction with thionyl chloride is carried out in the presence of pyridine.

It is impossible, however, that this statement of the orientation rules is accurate. Their extension and correction require a discussion of mechanism, which we shall give only in outline since further study has been undertaken with the aid of radioactive halogens.

We assume that with all the reagents under consideration the first step is the formation of an ester-halide, Alk·O·PCl_2, Alk·O·SOCl, etc.: many such compounds have been isolated. These ester-halides are all capable of ionising one of their halogen atoms; and, as Kenyon and Phillips have suggested (*loc. cit.*), this tendency is increased by pyridine owing to the production of pyridinium halides. The ester-halides can also undergo intramolecular "rearrangement" with the elimination of an organic oxide or oxyhalide. On the whole the phosphorus halides ionise more readily, and rearrange less readily, than the thionyl halides. Contrary to a suggestion of Kenyon and Phillips (*loc. cit.*), the secret of the peculiar behaviour of the phenyl substituent is that, owing to its capacity for electromeric electron-release, it loosens the C·O bond of the ester-halide, and so promotes rearrangement:



. Now, ionisation may be followed by either bimolecular or unimolecular substitution (S_N2 or S_N1); which sequel actually obtains may be expected to depend on the structure and the solvent in accordance with established principles; and bimolecular substitution will lead to inversion, whilst unimolecular substitution will produce inversion with racemisation; the alternative is an intramolecular nucleophilic change (S_Ni) which will retain the original configuration (cf. sub-section B, 1). The matter is illustrated with reference to the thionyl chloride reaction *:



It will be realised that what we have here referred to as a "rearrangement" is a nucleophilic substitution belonging to the category of the "four-atom problem": two covalencies are exchanged.

* The decomposition of alkyl chloroformates may be regarded similarly (read C for S in the above scheme). Harford, Kenyon, and Phillips have shown that configuration is retained when these esters are heated without a basic solvent, but inverted when they are decomposed in pyridine (J., 1933, 179).

These considerations allow us to interpret the optical results of halogenations in a more consistent manner than would have been possible on the basis of an unsupported application of the approximate empirical rules. We give some examples.

α-Hydroxy-α-phenylpropionic acid has been converted into the chloro-acid with change in the sign of rotation by means of phosphorus pentachloride, and without change by means of thionyl chloride; similar results have been obtained by the use of the ethyl esters in place of free acids (McKenzie and Clough, *J.*, 1910, **97**, 1016, 2564). Since a phenyl group is attached at the seat of substitution, this relationship is normal; and the rules tell us that phosphorus pentachloride causes inversion of configuration whilst thionyl chloride does not. Like signs of rotation therefore correspond to like configurations.

Ethyl α-hydroxy-α-naphthylacetate has been shown to yield a chloro-ester with an altered sign of rotation when the reagent is phosphorus pentachloride, and with a retained sign when it is thionyl chloride either alone or with pyridine; similar results have been obtained with the menthyl ester (McKenzie and Gow, J., 1933, **32**, 705). This relationship is abnormal, and is not covered by the rules: we usually find, either that all three reagents behave similarly, or that the first two act alike and the third oppositely: in this case the last two act alike and the first oppositely, so it has to be decided wherein the anomaly lies. As to this, the theory shows that, since the α-naphthyl group releases electrons more strongly than phenyl, the presence of the former group in place of the latter might promote the intramolecular change (S_Ni) in place of the more normal substitution (S_N2 or S_N1), but could not act in the opposite way; hence the anomalous reaction is the one involving thionyl chloride and pyridine, which in this case proceeds by rearrangement with retention of configuration. Therefore, for these compounds also, like signs of rotation signify corresponding configurations.

As a final example we may contrast the behaviour of α-phenylethyl alcohol with its homologue α-phenyl-*n*-amyl alcohol. The former reacts with phosphorus pentachloride with a change in the sign of rotation, and with thionyl chloride without a change; the latter reacts with both chlorinating agents without any change of sign, although the substitution brought about by phosphorus pentachloride is characterised by considerable racemisation (Levene and Mikeska, *J. Biol. Chem.*, 1926, **70**, 355). Now in most cases in which the two reagents behave in an optically similar manner we know that they both cause inversion; but α-phenyl-*n*-amyl alcohol is an exception, as the theory clearly indicates: not only does the amyl group promote better than methyl those electronic conditions which facilitate reaction S_Ni, but also it diminishes the tendency to the ionisation necessary for reactions S_N2 and S_N1. It follows that for the higher homologue the predominating mechanism is S_N1, and that both reagents substitute with preferential retention of configuration; although the racemisation observed with phosphorus pentachloride suggests that in this case the change from substitution to internal rearrangement is far from complete.

By means of these and similar arguments it is possible to establish configurational correspondence within the following sets of compounds :—

(1) β-n-*Butyl Series.*—(+)Alcohol, (+)Chloride, (+)Bromide.
(2) β-n-*Amyl Series.*—(+)Alcohol, (+)Chloride.
(3) *α-Phenyl-n-propyl Series.*—(+)Alcohol, (+)Chloride.
(4) *α-Phenyl-*n*-butyl Series.*—(+)Alcohol, (+)Chloride.
(5) *α-Phenyl*iso*butyl Series.*—(+)Alcohol, (+)Chloride.
(6) *α-Phenyl-*n*-amyl Series.*—(+)Alcohol, (+)Chloride.
(7) *α-Substituted α-Phenyl*iso*valeric Acids.*—(+)α-Hydroxy-, (+)α-Chloro-.
(8) *Ethyl and Menthyl α-Substituted α-Naphthylacetates.*—(+)α-Hydroxy-, (+)α-Chloro-.
(9) *αα′-Disubstituted Succinic Esters.*—(+)Methyl tartrate, (+)Ethyl tartrate, (+)Methyl chloromalate, (+)Ethyl chloromalate, (+)Ethyl bromomalate.

References.—(1) Le Bel, *Bull. Soc. chim.*, 1892, **7**, 552; 1893, [iii], **9**, 676; Kenyon, Phillips, and Pittman, J., 1935, 1072. (2) Le Bel, *locc. cit.* (3)—(6) Levene and Mikeska, *locc. cit.* (7) Walden, *Ber.* 1895, **28**, 2768. (8) McKenzie and Gow, *loc. cit.* (9) Walden, *Z. physikal. Chem.*, 1906, **55**, 42; *J. Russ. Phys. Chem. Soc.*, 1898, **30**, 522.

(2) *Replacements by Means of Hydrogen Halides.*—The configurative relations established in the preceding sections enable us to specify the steric course of a number of reactions in which hydrogen halides have been used in order to introduce halogen in place of hydroxyl. The following is a list of these substitutions. In all cases configuration is inverted; and, where any evidence as to the rotatory power of the optically pure halide exists, the indication is that more or less considerable racemisation occurs.

Substitutions with Inversion: Reagents and Hydroxy-compounds.

Hydrogen Chloride.—β-*n*-Amyl alcohol (2), β-*n*-Octyl alcohol (2), α-Phenylethyl alcohol (2), α-Phenyl-*n*-propyl alcohol (2), β-Hydroxy-β-phenylpropionic acid (3).

Hydrogen Bromide.—β-*n*-Butyl alcohol (6), β-*n*-Octyl alcohol (2, 4), α-Phenylethyl alcohol (7), α-Phenyl-*n*-propyl alcohol (5), α-Hydroxy-β-phenylpropionic acid (1), Methyl α-hydroxy-β-phenylpropionate (1).

Hydrogen Iodide.—β-*n*-Octyl alcohol (2).

References.—(1) McKenzie and Humphries, *loc. cit.* (2) Pickard and Kenyon, J., 1911, **99**, 45. (3) McKenzie and Barrow, *loc. cit.* (4), (5) Levene and Mikeska, *locc. cit.* (6) Kenyon, Phillips, and Pittman, *loc. cit.* (7) Hughes, Ingold, and Scott, this vol., p. 1201.

The expected mechanisms are quite similar to those illustrated with reference to the halides of phosphorus and sulphur. In the presence of strongly electron-releasing groups, and under conditions inhibitory to ionisation, we may expect a configuration-preserving "rearrangement" of a hydrogen-bond complex; otherwise an oxonium ion should be formed, the bimolecular or unimolecular substitution of which should produce inversion:

$$\geqslant C{\cdot}OH \longrightarrow \geqslant C{<}^{OH}_{Cl}{>}H \longrightarrow \geqslant C{-}Cl + H_2O \quad \text{(Retention)} \qquad (S_Ni)$$

$$\downarrow$$

$$\geqslant C{\cdot}OH \longrightarrow \geqslant C{\cdot}\overset{+}{O}H_2 + \overset{-}{Cl} \longrightarrow Cl{-}C\leqslant + H_2O \quad \text{(Inversion)} \qquad (S_N2)$$

$$\downarrow$$

$$\geqslant \overset{+}{C} + OH_2 + \overset{-}{Cl} \longrightarrow Cl{-}C\leqslant + H_2O \quad \text{(Predominating inversion)} \qquad (S_N1)$$

The bimolecular substitution (S_N2) corresponds to Meer and Polanyi's "positive mechanism," but contrary to these authors, we here represent it as proceeding always and in principle with an inversion of configuration.

From the examples tabulated above it would appear that the internal mechanism (S_Ni) is not at all commonly followed: we hope to realise it, but expect to do so only for specially chosen systems. There can be no doubt that, for all aliphatic, as well as the simpler aromatic, secondary alcohols, inversion is the rule: for these the mechanism is either the bimolecular (S_N2) or the unimolecular (S_N1) substitution of the oxonium ion; *a fortiori* the same statement must be true for primary alcohols.

These two mechanisms should in principle be distinguishable kinetically, the former as a third-order, the latter as a second-order, reaction: the rate of the S_N2 process should be proportional to the product of the activities of the alcohol, hydrogen ions and chloride ions; whilst that of the S_N1 reaction should vary as the product of the activities of the alcohol and hydrogen ions only—if we may assume, as usual, that the final ionic association is rapid. Several kinetic investigations have been carried out, but, in the non-aqueous solvents which are usually employed, the liberated water has a marked effect on the speed, and for this and other reasons the relation of activity to concentration is far from straightforward (Kilpi, *Z. physikal. Chem.*, 1914, **86**, 427; 1929, *A*, **141**, 424; **142**, 195; 1933, *A*, **166**, 285; Norris, *ibid.*, 1927, **130**, 600; *Rec. trav. chim.*, 1929, **45**, 885; Levene and Rothen, *J. Biol. Chem.*, 1929, **81**, 359; Bennett and Mosses, J., 1931, 2956; Bennett and Reynolds, J., 1935, 131; Hinshelwood, *ibid.*, p. 599). (The effect of water is to be expected, since the large energy of hydration of the hydrogen ion must reduce its activity.) It is noteworthy, however, that Kilpi, whose experiments related to the action of hydrogen chloride on ethyl

and *n*-propyl alcohols in the absence of a solvent, concluded that his results could be interpreted by assuming that the rate varied as the activities of hydrogen and chloride ions: since the alcohols were present in excess, this indicates a third-order reaction such as S_N2. Bennett and his collaborators, who examined the action of hydrogen bromide on a large number of alcohols in aqueous phenol as solvent, obtained second-order constants such as mechanism S_N1 would require; however, the constants varied so considerably with the initial concentrations of reactants that this indication of mechanism cannot be regarded as conclusive. Bennett showed that the reaction is accelerated by electron accession; but although this must be true for mechanism S_N1, it may also be true for mechanism S_N2.

In spite of these uncertainties sufficient is clear concerning mechanism to enable us to base several further assignments of relative configurations on results which have been obtained in the treatment of optically active alcohols with hydrogen halides:

(1) β-n-*Butyl Series.*—(+)Alcohol, (+)Iodide.
(2) β-n-*Amyl Series.*—(+)Alcohol, (+)Iodide.
(3) β-n-*Hexyl Series.*—(+)Alcohol, (+)Iodide.
(4) γ-n-*Nonyl Series.*—(+)Alcohol, (+)Chloride,(+)Bromide, (+)Iodide.
(5) α-*Phenyl*-n-*propyl Series.*—(+)Alcohol, (+)Bromide.

References.—(1)—(4) Pickard and Kenyon, *loc. cit.* (5) Levene and Mikeska, *J. Biol. Chem.*, 1926, **70**, 355.

SUMMARY.

(1) The known relationships between the mechanism of aliphatic substitution and the structures of the compounds substituted form a starting point for the investigation of the laws governing the steric orientation of substitution. Experimental investigation of the optical effect of substitution at an asymmetric carbon atom is most valuable if the conditions are defined by a previous examination of the reaction kinetics; and, as a result of work carried out on this plan, certain general principles relating to the orientation of substitution are advanced, although detailed discussion is confined to the reciprocal replacements of ·Hal and ·OR.

(2) The accumulation of electron-releasing alkyl groups, and still more of aryl groups, at the seat of substitution in an organic halide for known reasons causes the suppression of bimolecular nucleophilic substitution and its supersession by the unimolecular reaction dependent on halogen ionisation. The electron-repelling carboxylate-ion group acts quite similarly, and the apparently complicated results recorded by previous workers (*e.g.*, Dawson) on the kinetics of the hydrolysis of halogeno-acids receive a simple explanation on this basis. The electron-attracting carboxyl group (undissociated), and likewise the ester and carboxylamide groups, act oppositely, as would be expected: they favour bimolecular substitution and inhibit the unimolecular process.

(3) Bimolecular substitution (S_N2 or S_E2) leads to inversion normally because of the exclusion principle, and independently of whether the electropolar forces in the compound substituted direct the reagent predominatingly to one side of the molecule or the other. (In aromatic substitution, as an application of the exclusion principle shows, the attack of the reagent must be lateral to the plane of the ring.)

(4) Unimolecular substitution in alkyl compounds leads normally to racemisation, because the intermediate ion has a plane of symmetry; but if the life of the ion is short, racemisation will be incomplete and will accompany a predominating inversion, owing to the circumstance that the separating ions shield each other; and since the life of an ion can be varied by altering the composition of the medium the degree of incompleteness of the racemisation should vary in a predictable way with such changes. An unsaturated substituent (*e.g.*, aryl) at the seat of substitution should increase the tendency to racemisation, because mesomerism confers additional stability on the planar ion. A charged substituent of neutralising sign (*e.g.*, a carboxylate-ion substituent in a cation) may stabilise a pyramidal configuration in the ion, and lead to eventual substitution with retention of form.

(5) Heterogeneous mechanisms of substitution arise in the hydrolysis of organic halogen compounds with silver oxide and silver salts. They appear to depend on a weakening of

the carbon–halogen bond by adsorption on the polar surface of an insoluble silver salt, and subsequent ionic fission of the bond on this surface through the attack of adsorbed silver ions. The stereochemical consequences are similar to those of the homogeneous mechanism dependent on ionisation (S_N1).

(6) Substitution dependent on internal rearrangements may lead to a retention of form if the point in the rearranging chain at which it recombines is insufficiently removed from the point at which it breaks loose to permit a simultaneous linking with both sides of the asymmetric atom.

(7) The rules mentioned in paragraphs (3), (4), and (5) for the steric orientation of nucleophilic aliphatic substitution are confirmed by reference to the hydrolysis and alcoholysis of β-*n*-octyl bromide, α-phenylethyl chloride, and α-bromopropionic acid, its methyl ester, and its anion, the reactions of these compounds having been investigated by the method indicated in paragraph (1).

(8) Previous investigations of the optical effects accompanying the hydrolysis or alcoholysis of optically active halogeno-acids and their derivatives are reviewed. In spite of the general lack of precise information concerning the conditions in which the observations were made, our orientation rules in most cases permit a determination to be made of the stereochemical relationship between factors and products. The assignments of relative configuration thus derived agree well with those of Frankland, who employed different principles.

(9) The assignments of configuration, reached as described above, determine the steric orientation of reactions in which hydroxyl is replaced by a halogen atom. A review of the orientations obtaining in the reactions in which phosphorus and thionyl halides have been employed indicates the general nature of the mechanisms at work. An ester-halide is first formed which may either internally rearrange with retention of stereochemical form, or ionise and thus substitute with inversion. The former mechanism is favoured by the release of electrons (*e.g.*, from aryl groups) to the seat of substitution, and the latter by those conditions which promote ionisation. Apparent anomalies are interpreted on this basis, and further assignments of relative configuration are made.

(10) Similar treatment is accorded to the reactions in which hydrogen halides are used to replace hydroxyl by halogen. The possible mechanisms include internal rearrangement of a hydrogen-bond complex with retention of form, and the ionisation of the complex followed by substitution with inversion. The ionic route is most commonly followed, and its consideration leads to some further assignments of configuration.

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258. *The Mechanism of Elimination Reactions. Part I. Unimolecular Olefin Formation from Alkyl Halides in Sulphur Dioxide and Formic Acid.*

By Edward D. Hughes, Christopher K. Ingold, and Alan D. Scott.

Substitution and elimination so often occur together that the duality of homogeneous mechanism established for substitution suggested the possibility of a similar duality for elimination: in substitution we have the bimolecular and unimolecular mechanisms already many times illustrated (*e.g.*, this vol., p. 1177), and thus the hitherto known bimolecular elimination (Hanhart and Ingold), *e.g.*,

$$OH^- + H{\cdot}CR_2{\cdot}CR_2{\cdot}X \longrightarrow H_2O + CR_2{:}CR_2 + X^-$$

might have a unimolecular counterpart, depending on the slow formation of an organic cation and the rapid liberation of a proton from the latter:

$$\begin{cases} H{\cdot}CR_2{\cdot}CR_2{\cdot}X \xrightarrow[(slow)]{} H{\cdot}CR_2{\cdot}CR_2^+ + X^- \\ H{\cdot}CR_2{\cdot}CR_2^+ \xrightarrow[(fast)]{} H^+ + CR_2{:}CR_2 \end{cases}$$

In this initial search for such a reaction, we avoided competition from unimolecular substitution by operating in the non-basic solvents sulphur dioxide and formic acid, both of which can ionise alkyl halides. The halides used were α-phenylethyl chloride and *tert.*-butyl chloride, which undergo unimolecular substitution in basic solvents, and have hydrogen in such a position that the cation if formed could eliminate it.

It is shown that in both solvents both halides come spontaneously into equilibrium with the appropriate olefin and hydrogen chloride. For α-phenylethyl chloride in formic acid the rate of the forward reaction agrees with the rate of racemisation sufficiently to suggest that the two experiments measure the same process. For *tert.*-butyl chloride the forward rate in dry formic acid is of the same order of magnitude as the rate of unimolecular hydrolysis in wet formic acid, and again the suggestion is that the process measured is the same, *viz.*, the rate of ionisation.

REPLACEMENT and elimination reactions in substitution products of paraffins so often occur side by side that it is difficult to make any close study of one process without taking stock of the other, and for this reason the series of papers now commenced represents only a continuation of a theme already partly developed. In a group of researches commenced 9 years ago and published mainly under the title "The Influence of Poles and Polar Linkings on the Course pursued by Elimination Reactions" we established a general mechanism of elimination (Hanhart and Ingold, J., 1927, 997) and traced its consequences in many fields of application. In the course of this work we found ourselves inevitably studying aliphatic substitution, and 3 years ago we made this subject the principal aim of the continued investigations, which are described chiefly in papers entitled "The Mechanism of Substitution at a Saturated Carbon Atom." In this field we have established multiplicity of mechanism (Hughes, Ingold, and Patel, J., 1933, 526), set up a general framework of theory (Hughes and Ingold, J., 1935, 244), and indicated or contributed numerous applications. During these investigations on substitution our knowledge concerning elimination has automatically grown, and now it seems opportune again to concentrate on that subject. The difference between the new attack and the old is this: instead of adding detail to the study of the one elimination mechanism the principal laws of which are already known, we now set ourselves to discover what mechanisms are possible and what factors control them, thus to prepare the way for a theory of eliminations as broad as that which has been established for substitutions.

In Hanhart and Ingold's mechanism of elimination, a reagent possessing basic properties extracts the protonic part of a combined hydrogen atom, whilst an electron-attracting group simultaneously separates in possession of an extra electron; it is necessary that the hydrogen atom and the electron-attractor shall be bound to adjacent carbon atoms in the original molecule in order that the atomic electron shells shall remain complete throughout the change. Two bonds are thus broken, but the reaction does not go in two stages: each bond-fission assists the other, the two comprising a single synchronised act. In the equation

$$X + H\vdots\!-\!CR_2\cdot CR_2\vdots\!-\!Y \longrightarrow XH + CR_2{:}CR_2 + Y \quad . \quad . \quad . \quad . \quad (E2)$$

the vertical lines indicate the direction of the electron transfers; the basic reagent X may be negatively charged or neutral, and the electron-attracting group Y may be formally neutral or positive; but after reaction the formal charge of X will be more positive by one unit, and that of Y more negative by one unit, than before.

The reaction is bimolecular, and hence we label it E2. In general it is experimentally of the second order. This has been established for $X = \overline{O}H$ in the case of ammonium, sulphonium, and halogen compounds, $Y = \overset{+}{N}R_3, \overset{+}{S}R_2$, Hal. (Hughes and Ingold, J., **1933**, 523, *et seq.*), *e.g.*,

$$\overline{O}H + H\cdot CHPh\cdot CH_2\cdot\overset{+}{N}Me_3 \longrightarrow H_2O + CHPh{:}CH_2 + NMe_3 \text{ (2nd Order; E2)}$$

We must point out, however, that mechanism E2 is not of necessity associated with second-order kinetics. In the above example a rather strongly basic reagent is employed, but, if

the hydrogen atom of the organic molecule is rendered sufficiently vulnerable by constitutional influences, a much weaker base will suffice, for instance, a solvent molecule. Introducing a *p*-nitro-group into the above ammonium cation, Hughes and Ingold (*loc. cit.*) observed the reaction :

$$H_2O + H{\cdot}CH(C_6H_4{\cdot}NO_2){\cdot}CH_2{\cdot}\overset{+}{N}Me_3 \longrightarrow H_3\overset{+}{O} + CH(C_6H_4{\cdot}NO_2){:}CH_2 + NMe_3$$

(1st order; E2)

which is of the first order in aqueous solution. (The reaction $H_3\overset{+}{O} + NMe_3 \longrightarrow H_2O + H\overset{+}{N}Me_3$ immediately removes NMe_3, and thus prevents its incursion into the elimination process as an additional basic reagent.) In spite of its kinetic order this reaction almost certainly pursues the bimolecular mechanism, E2, as is indicated, for instance, by the large increases of speed which are observed when small amounts of some stronger base than water, *e.g.*, trimethylamine, are added initially.

There are, however, many elimination reactions which cannot pursue mechanism E2. For instance, αα-diphenylethyl chloride decomposes into diphenylethylene and hydrogen chloride in the absence of any substance likely to act as a basic reagent (Schoepfle and Ryan, *J. Amer. Chem. Soc.*, 1930, **52**, 4021).

One mechanism which we imagine to be rather generally available would consist in the slow ionisation of the paraffin derivative (the negative charge going to the electron-attracting group) followed by the rapid ejection of a proton from the hydrocarbon cation :

$$\left.\begin{array}{l} H{\cdot}CR_2{\cdot}CR_2 \vdots\!-\!Y \xrightarrow[\text{slow}]{} H{\cdot}CR_2{\cdot}\overset{+}{C}R_2 + \overset{-}{Y} \\ H\vdots\!-\!CR_2{\cdot}\overset{+}{C}R_2 \xrightarrow[\text{fast}]{} \overset{+}{H} + CR_2{:}CR_2 \end{array}\right\} \quad . \quad . \quad . \quad . \quad (E1)$$

This reaction, which we label E1, may be described as unimolecular, and should be of the first order in dilute solution. Its rate-controlling stage is the preliminary ionisation exactly as in unimolecular nucleophilic substitution (S_N1). It should be available to any paraffin derivative which is sufficiently easily ionised to undergo this form of substitution, and which also possesses the hydrogen atom necessary for the elimination, *e.g.*, to most secondary and tertiary alkyl halides.

We have attempted to obtain evidence of the operation of this mechanism in more easily controllable examples than that of αα-diphenylethyl chloride, *viz.*, α-phenylethyl chloride, and, to some extent, *tert.*-butyl chloride. Both these compounds undergo unimolecular nucleophilic substitution (S_N1) at speeds convenient for measurement, and both have hydrogen in the right position for elimination. Our choice of solvents was guided by the following considerations. It was necessary that the solvents should be good ionising media for alkyl halides. Water at first suggested itself, and it will be shown in Part II that unimolecular elimination (mechanism E1) can in fact be demonstrated in aqueous solvents; but in this first investigation it seemed desirable to avoid water, since any such basic solvent might, as illustrated above, promote bimolecular elimination (mechanism E2) as a pseudo-first-order reaction, which it would be difficult kinetically to distinguish from the mechanism we wished to study. The solvents actually employed were sulphur dioxide and formic acid. Neither is perceptibly basic, and both are supposed to have the ability to ionise certain alkyl halides, including α-phenylethyl chloride.

The most important previous experiment on α-phenylethyl chloride in sulphur dioxide solution is that of Bergmann and Polanyi (*Naturwiss.*, 1933, **21**, 378), who showed that the rate of racemisation of the optically active compound was substantially unaffected by added chloride ions. We have tried to determine whether this unimolecular racemisation can be accounted for by the reversible formation of styrene, but all that can be said is that we have established the possibility of this explanation. There certainly is an equilibrium

$$CHPhMeCl \rightleftharpoons CHPh{:}CH_2 + HCl \quad . \quad . \quad . \quad . \quad . \quad (I)$$

in which the principal component is that on the left. The evidence of this is as follows. When α-phenylethyl chloride was kept for some time at 0° in solution in sulphur dioxide, the material remaining after removal of the solvent yielded, along with much unchanged chloride, a small proportion (order 10^{-3}) of styrene, or, in some experiments, polystyrene. When, on the other hand, styrene and a slight excess of hydrogen chloride were together dissolved in sulphur dioxide the subsequently isolated materials were α-phenylethyl chloride together with a similarly small quantity of styrene and/or polystyrene. The addition of bromine to a solution of α-phenylethyl chloride in sulphur dioxide resulted in the complete conversion of the chloride partly into crystalline styrene dibromide and partly into an oil which was probably styrene chlorobromide. In order to eliminate the complication arising from halogen interchange between the added bromine and the liberated hydrogen chloride, the same experiment was repeated with α-phenylethyl bromide and bromine; the yield of crystalline styrene dibromide was now quantitative. Having thus demonstrated the equilibrium formulated above, the next step should have been to measure the rate of the forward reaction for comparison with the rate of racemisation; but this we could not do owing to the one-sidedness of the equilibrium. The electrical conduction of dry hydrogen chloride in "conductivity" sulphur dioxide is too slight to enable such measurements to be used for this purpose. It may be mentioned, in view of the reported conductivity of some alkyl halides in sulphur dioxide, that pure α-phenylethyl chloride in freshly prepared solution in pure sulphur dioxide has no measurable conductivity.

The reaction in formic acid is in some respects more amenable to treatment. Bodendorf and Böhme had shown (*Annalen*, 1935, **516**, 1) that optically active α-phenylethyl chloride undergoes unimolecular racemisation in this solvent more rapidly than in sulphur dioxide. The occurrence of the elimination in formic acid can most easily be demonstrated in the following way. Although α-phenylethyl chloride and styrene are miscible with formic acid, polystyrene has only a limited solubility; therefore, if a solution of α-phenylethyl chloride of more than a certain concentration (10% suffices) is kept, a layer of polystyrene * begins to separate, and this layer continues to accumulate for a considerable time. Its formation may be assisted by the passage of nitrogen which aspirates away a good deal of the eliminated hydrogen chloride. In more dilute solution (*e.g.*, 5%) no polystyrene separates, and for such solutions our qualitative investigation of the forward and reverse reactions followed the lines already described for sulphur dioxide. No matter whether the starting materials consisted of α-phenylethyl chloride or of styrene and hydrogen chloride, the most abundant product was always α-phenylethyl chloride. However, polystyrene was obtained in considerably greater amounts than from the sulphur dioxide solutions, although styrene itself could be found only occasionally and in small quantity. Inasmuch as the formic acid employed was not completely free from water, a small amount of α-phenylethyl alcohol was produced; and this substance when dissolved along with an equivalent of hydrogen chloride in formic acid gave mixtures entirely similar to those obtained from α-phenylethyl chloride or from styrene and hydrogen chloride. At this point we proceeded to a more quantitative study.

A 0·15*M*-solution of α-phenylethyl chloride in formic acid came into a nearly steady state with 34% of the chlorine present in the form of free hydrogen chloride. A slightly higher figure was obtained when the starting materials were styrene and hydrogen chloride. Clearly, therefore, this was a case in which we could estimate the initial rate of production of chloride ions, *i.e.*, the rate of the forward reaction in the absence of disturbances due to reversibility. The extrapolated initial rate at 16·9° was 0·0009 $sec.^{-1}$. The rate of racemisation, interpolated to 16·9° from Bodendorf and Böhme's rates at 0° and 25°, is 0·0013 $sec.^{-1}$. Considering the errors and the difference of method, the agreement is striking, and may be taken to indicate the identity of the process the rate of which is measured by these two types of experiment.

In the case of *tert.*-butyl chloride, the equilibrium $CMe_3{\cdot}Cl \rightleftharpoons CMe_2{:}CH_2 + HCl$ in sulphur dioxide strongly favours the left-hand component, and our evidence of the

* It contains some α-phenylethyl chloride, which, when the solution become inhomogeneous, is partitioned between the two phases.

forward reaction consists simply in the fact that the addition of bromine causes complete decomposition of the alkyl chloride with the formation of *iso*butylene dibromide in high yield. The behaviour of *tert.*-butyl chloride in solution in anhydrous formic acid is described in an accompanying paper (Bateman and Hughes, this vol., p. 1187). *iso*Butylene and hydrogen chloride were formed, and, at the concentrations used, 7% of hydrogen chloride was present at equilibrium. Furthermore, the initial rate of development of hydrogen chloride in this reaction, although difficult to estimate, was at least roughly the same as in the process in which the alkyl chloride undergoes unimolecular hydrolysis in formic acid as the solvent. Again we may assume the identity of the rate-controlling process in these two reactions.

Our opinion is that the mechanism of olefin elimination in the cases cited is that in which the rate-controlling stage is halogen-ionisation (E1), but we do not claim that the evidence advanced in this paper constitutes a flawless proof of this. The simplest alternatives are, first, that the mechanism depends on the prior transfer of a proton to the solvent (E2); and second, that it consists in a single-stage intramolecular elimination of hydrogen chloride (Ei). The former possibility can be almost certainly excluded because the solvents employed have practically no affinity for protons (witness, *e.g.*, the negligible conductivity of hydrogen chloride in sulphur dioxide); and because we can show (following papers) that, even in aqueous solvents, which have a strong affinity for protons, the mechanism remains dependent on halogen-ionisation, and not on proton-transfer. All we can say of the intramolecular alternative is that it seems to provide too slight and indirect a rôle for the solvent, which obviously plays a fundamental part in the reactions described. Our preferred hypothesis (Ei) agrees with the views of Bergmann and Polanyi and of Bodendorf and Böhme to the effect that their observations on racemisation measure the rate of ionisation of the halide, even although we now know that racemisation arises in a regeneration of the halide from a non-asymmetric olefin : in mechanism E1 the instability of an alkyl cation containing a labile proton is made responsible for the production of the olefin.

EXPERIMENTAL.

α-Phenylethyl Chloride and Bromide in Sulphur Dioxide.—The chloride was prepared from α-phenylethyl alcohol and thionyl chloride. It could not be dried by means of phosphoric oxide as this brought about decomposition, and the material was found to undergo decomposition slowly if any hydrogen chloride remained in it. It was therefore dried with potassium carbonate, and finally distilled from a small amount of this reagent in a good vacuum (Found : C, 68·3; H, 6·4; Cl, 25·2. Calc. : C, 68·3; H, 6·4; Cl, 25·3%). If required for conductivity work it was subjected to a non-ebullient distillation in a vacuum, in order to eliminate the traces of saline material which get carried over in any ordinary distillation.

The bromide was prepared from the alcohol and hydrogen bromide, and purified by similar methods, except that no experiments on conductivity were done with it.

The sulphur dioxide, drawn from a syphon, was dried in the gas phase by passage over phosphoric oxide, and then distilled from one to another of a row of bulbs on an exhausted all-glass gas-line. Three bulbs, each containing phosphoric oxide, were used to dry the reagent in the liquid phase, and in each bulb contact for two days was allowed. One of the other bulbs contained the alkyl halide, and this could be made to receive the sulphur dioxide (10—20 parts) by cooling in liquid air whilst the drying bulb containing the solvent was immersed in solid carbon dioxide. When sulphur dioxide was required for tests of conductivity the same process of purification was gone through, with the addition that, before the first drying, the gas from the syphon was bubbled through acidified dilute barium chloride solution in order to remove sulphur trioxide.

In the experiments on the products of the spontaneous reaction in solution, styrene was obtained in the first runnings of distillation, and the polystyrene, if at all, in the least volatile portion. The styrene was finally isolated and identified always as its dibromide (mixed m. p.). The main central fraction in these distillations was always the α-phenylethyl halide, which was identified by its b. p. and analytical data. In the experiments in which bromine was added to solutions of α-phenylethyl chloride or bromide, crystalline styrene dibromide separated during evaporation of the sulphur dioxide. The material thus obtained from α-phenylethyl chloride contained a little oil, and only had the correct m. p. after being washed with light petroleum.

The product obtained from α-phenylethyl bromide, on the other hand, had the right m. p. *without purification.**

The sulphur dioxide used for the tests of conductivity had itself a specific conductivity of about 6×10^{-7} mho-cm.$^{-1}$. The resistance of the cell filled with this sulphur dioxide was slightly increased when pure α-phenylethyl chloride (about 5%) was added. The conductivity of a solution 0·015*M* with respect to hydrogen chloride was 10×10^{-7} mho-cm.$^{-1}$, which leaves a balance of 4×10^{-7} mho-cm.$^{-1}$ for the dissolved hydrogen chloride. The hydrogen chloride used in this experiment and others of a similar kind was dried in the gas phase with phosphoric oxide, with which it was enclosed in a tube for some days, to be subsequently swept into the cooled conductivity cell with a little " conductivity " sulphur dioxide. The concentration was determined by noting the volume of the solution in the cell which had been calibrated for volume, and, after the resistance measurement, distilling the whole contents of the cell into chloride-free potassium hydroxide; the chloride was then estimated gravimetrically. When a small amount of water is added to a solution of α-phenylethyl chloride in sulphur dioxide, the conductivity undergoes a rapid and marked increase, owing presumably to hydrolysis and the formation of hydroxonium chloride.

The rate of racemisation of *l*-α-phenylethyl chloride in dry liquid sulphur dioxide was measured at 26·5°. The reaction followed a first-order law, the rate constant being $1{\cdot}15 \times 10^{-4}$ sec.$^{-1}$, a figure which agrees sufficiently well with Bergmann and Polanyi's, having regard to the difference of temperature between their experiment and ours. A parallel experiment was carried out in which water (0·7% by vol.) was added to the solvent. The rate constant was now $1{\cdot}08 \times 10^{-4}$ sec.$^{-1}$.

tert.-*Butyl Chloride in Sulphur Dioxide*.—A solution of the chloride (10 c.c.) and bromine (4 c.c.) in sulphur dioxide (60 c.c.) was kept at room temperature for 14 hours. It was then nearly colourless. The sulphur dioxide was removed by distillation along with a considerable amount of hydrogen chloride. No *tert.*-butyl chloride was recovered, but the residual oil on distillation yielded a liquid of constant b. p. 42°/16 mm., which is proved by analysis to be *iso*butylene dibromide (Found: C, 22·9; H, 3·6; Br, 73·7. Calc.: C, 22·2; H, 3·7; Br, 74·1%).

α-*Phenylethyl Chloride in Formic Acid*.—The experiments of Bodendorf and Böhme, with whose results we wished to compare our own, were conducted with Kahlbaum's " anhydrous " formic acid, the freezing point of which they specified, and therefore we used similar material; as mentioned by Bateman and Hughes (this vol., p. 1190), it is not in fact perfectly anhydrous.

A few details may be added to the description, given in the introduction, of the qualitative experiments. A 10% solution of α-phenylethyl chloride in formic acid became heterogeneous in about 0·5 hour at the room temperature, and the polystyrene layer which rose to the surface increased in size over a period of one week. The experiment was then stopped and the yield of polystyrene, b. p. about 275°/16 mm. was 65% (Found: C, 90·7; H, 7·7. Calc.: C, 92·3; H, 7·7%), and a fraction was obtained the b. p. and analysis of which suggested a mixture of α-phenylethyl chloride and alcohol. During the experiment a stream of nitrogen, saturated with formic acid vapour, was passed through the solution, and hydrogen chloride was carried away and caught in alkali. In the experiments with the more dilute solutions, which remained homogeneous, the solutes were isolated by extraction with carbon tetrachloride after addition of water. Styrene and polystyrene were obtained from the head and tail portions of the subsequent distillation and the former identified as its dibromide. The centre fractions, although essentially α-phenylethyl chloride, always contained oxygen. The proportion of chloride was estimated by taking advantage of the rapid unimolecular hydrolysis of this substance: the α-phenylethyl chloride fraction was shaken with water, and the chloride ion determined. The proportion of α-phenylethyl alcohol was measured by treating the fraction with thionyl chloride, and then estimating the rapidly hydrolysable chloride as just described. The compositions were in the neighbourhood: α-phenylethyl chloride, 80%; α-phenylethyl alcohol, 10%; unidentified, 10%.

Kinetic and Equilibrium Measurements.—α-Phenylethyl chloride (2 c.c.) was dissolved in formic acid (100 c.c.) at 16·90° ± 0·02°. At intervals, portions of 5 c.c. were withdrawn and

* A crystalline *dimeride* of styrene was obtained in one experiment, in which α-phenylethyl bromide was allowed spontaneously to decompose in sulphur dioxide. A mixture of α-phenylethyl bromide and polystyrene was isolated, which on keeping deposited a crystalline substance. After crystallisation from light petroleum this had m. p. 105° (Found: *M*, 214, 216; C, 91·9; H, 7·6. $C_{16}H_{16}$ requires *M*, 208; C, 92·3; H, 7·7%).

run into carbon tetrachloride (50 c.c.). The carbon tetrachloride was extracted with water (total of 60 c.c.) and the chloride-ion content of the aqueous extract was estimated by Volhard's method. The total halide concentration was also determined by a Volhard titration, after running 5 c.c. of the reaction mixture into alcohol: α-phenylethyl chloride reacts quantitatively with silver nitrate under these conditions. In the table, a is the initial concentration of α-phenylethyl chloride, x the concentration of hydrogen chloride after reaction for t seconds, x_∞ the equilibrium concentration of hydrogen chloride, k_1' the first order "constant" calculated from the formula $k_1' = (1/t) . \log_e \{a/(a - x)\}$, which neglects reversibility, and k_1 the constant obtained from the integrated rate equation of a first-order reaction with second-order reversal ($A \underset{k_2}{\overset{k_1}{\rightleftharpoons}} B + C$):

$$k_1 = x_\infty/t(2a - x_\infty) . \log_e[\{ax_\infty + x(a - x_\infty)\}/\{a(x_\infty - x)\}].$$

The quantities a, x, and x_∞ are expressed as equivalent c.c of 0·0295N-ammonium thiocyanate per 5 c.c. of the reaction mixture.

$a = 25·14$; $x_\infty = 8·20$.

....	62	98	132	180	240	300	365	420	480	600
x	1·40	2·02	2·72	3·32	4·28	5·02	5·68	6·10	6·75	7·20
$10^4k_1'$	9·25	8·53	8·65	7·87	7·76	7·44	7·02	6·61	6·52	5·62
10^4k_1	9·31	8·68	8·92	8·22	8·23	8·38	8·33	8·20	8·89	8·33

Solutions of (*a*) styrene and (*b*) α-phenylethyl alcohol in "Kahlbaum" formic acid containing hydrogen chloride were kept in a thermostat at 16·9°. The concentration of chloride ions at equilibrium, and the total halide concentration, were determined in each case by the methods described for the kinetic measurements. The results were as follows:

(*a*).		(*b*).	
$[\text{Styrene}]_{\text{initial}}$	= 0·155M	$[\alpha\text{-Phenylethyl alcohol}]_{\text{initial}}$	= 0·145M
$[\text{Cl}]_{\text{total}}$	= 0·126M	$[\text{Cl}]_{\text{total}}$	= 0·126M
$[\bar{\text{Cl}}]_{\text{equilibrium}}$	= 0·0503M	$[\bar{\text{Cl}}]_{\text{equilibrium}}$	= 0·049M

University College, London. [*Received, April 24th*, 1937

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259. *The Mechanism of Elimination Reactions. Part II. Unimolecular Olefin Formation from* sec.*-Octyl Halides in Aqueous Alcohol. A New Criterion of Mechanism.*

By Edward D. Hughes, Christopher K. Ingold, and Uriel G. Shapiro.

Unimolecular elimination having been observed in non-aqueous solvents (this vol., p. 1271), it was next sought as accompaniment of unimolecular substitution in the aqueous hydrolysis of secondary and tertiary alkyl halides. In this work β-*n*-octyl chloride and bromide were used. The reaction was found, and its kinetic properties demonstrated.

It follows from the mechanism assumed for unimolecular substitution and elimination that, for the same alkyl group, a change in the halogen atom should have a direct and possibly large effect on the rates of the individual simultaneous reactions, but only an indirect and relatively small effect on the ratio of the rates. Consistently we find, on passing from chloride to bromide, that the rates are increased about 35-fold, whilst the ratio remains constant to within 10%.

Evidence was given in Part I that in certain non-aqueous solvents alkyl halides can yield olefins by a unimolecular mechanism dependent on slow halogen-ionisation followed by the rapid loss of a proton from the unstable cation thus formed:

$$\left.\begin{aligned} \text{CHR}_2\cdot\text{CR}_2\cdot\text{Hal} &\xrightarrow{\text{slow}} \text{CHR}_2\cdot\overset{+}{\text{C}}\text{R}_2 + \overset{-}{\text{Hal}} \\ \text{CHR}_2\cdot\overset{+}{\text{C}}\text{R}_2 &\xrightarrow{\text{fast}} \text{CR}_2\text{:CR}_2 + \text{H}^+ \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad (\text{E1})$$

In this and the immediately following papers we describe a search for the same reaction in aqueous solvents; and we also develop an independent proof of mechanism.

In aqueous, or, more generally, in hydroxylic, solvents there are other ways than the

loss of a proton in which the assumed cation can be converted into a stable compound: *unimolecular elimination, if it occurs, must be an accompaniment of unimolecular hydrolytic substitution.* Unimolecular substitution appears to be general for secondary and tertiary alkyl halides, and it was therefore amongst the reactions of these compounds that we commenced the search for unimolecular elimination. The secondary compounds which we have examined with respect to unimolecular hydrolytic substitution include *iso*propyl and β-*n*-octyl halides, and it is in the case of the latter that we succeeded first in observing simultaneous unimolecular elimination.

The hydrolytic reactions of β-*n*-octyl bromide were examined by Hughes and Shapiro (this vol., p. 1192) in 60% aqueous ethyl alcohol at 80°. In alkaline solution they found a unimolecular substitution (S_N1), and a bimolecular substitution (S_N2), both consisting partly in hydrolysis and partly in alcoholysis, together with a bimolecular olefin elimination (E2). In acid solution the two bimolecular reactions became negligible, leaving the unimolecular substitution (S_N1) in control. Now the progress of this reaction was followed by noting the development of acidity, and hence its measured rate would include that of any *simultaneous unimolecular elimination.* Our first step, therefore, was to determine whether any of the total first-order reaction actually resulted in the production of olefin; and we found that 10% of it did so. Anticipating the evidence that the olefin thus obtained is actually the product of a unimolecular elimination (E1), we may set down the proportions in which the various reactions take place side by side, either in an acid medium, or in a sensibly constant 0·8*N*-concentration of alkali:

Acid—1st Order 100% < S_N1 90·3% ; E1 9·7%

0·8*N*-Alkali < 1st Order 7·25% < S_N1 6·5%, E1 0·7% ; 2nd Order 92·75% < S_N2 41·7%, E2 51·1%

Substitution 48·2% ; Elimination 51·8%

The rate constants of the four reactions at 80° in the solvent mentioned are as follows:

S_N1 $10^4k_1 = 0{\cdot}466$ sec.$^{-1}$	S_N2 $10^4k_2 = 3{\cdot}58$ sec.$^{-1}$g.-mol.$^{-1}$l.
E1 $10^4k_1 = 0{\cdot}050$ sec.$^{-1}$	E2 $10^4k_2 = 4{\cdot}39$ sec.$^{-1}$g.-mol.$^{-1}$l.

Further experiments have been carried out at 100° in the same solvent, and with β-*n*-octyl chloride as well as the bromide.

It was necessary next to prove that the formation of octylene in acid solution is in fact kinetically of the first order: this cannot be regarded as established by the proved first order of the total reaction, since the elimination is a relatively small part of the complete process. The reaction was therefore followed by estimating, not the acidity or the bromide ions as heretofore, but the olefin, the analysis being carried out by addition of bromine. The logarithms of the olefin concentrations gave linear plots against the time to within the error of analysis, and the rate constants derived as usual from the slopes of the graphs agreed with those deduced from measurements of acidity or of halide ions. Thus, not only is the total reaction of the first order, but so also is its minor constituent, the elimination; and the amount of olefin formed at any time is a constant fraction of the quantity of halide decomposed.

A test of mechanism follows from a comparison of the suggested mechanisms for unimolecular elimination and unimolecular substitution. Both assume the same rate-controlling process, *viz.*, the slow ionisation of the alkyl halide. The postulated rapid steps differ, but they are both assumed to be reactions of the organic cation, the anion not being concerned. It follows that the ratio of the rates with which the cation, when once formed, will decompose in the two possible ways should be independent of the nature of the anion. The reactions may be written:

$$\mathrm{R{\cdot}X} \xrightarrow[\text{(slow)}]{} \overset{+}{\mathrm{R}} + \overset{-}{\mathrm{X}} \begin{cases} \overset{+}{\mathrm{R}} \xrightarrow[\mathrm{H_2O}]{} \mathrm{R{\cdot}OH} + \overset{+}{\mathrm{H}}\ (\text{fast}) \quad . \quad . \quad . \quad . \quad (S_N1) \\ \overset{+}{\mathrm{R}} \longrightarrow \text{Olefin} + \overset{+}{\mathrm{H}}\ (\text{fast}) \quad . \quad . \quad . \quad . \quad (E1) \end{cases}$$

The rate of ionisation of the alkyl halide is the rate of the total first-order decomposition (k_1):

$$k_{\text{ionisation}} = k_1 = k_{S_N1} + k_{E1}$$

For a given solvent and temperature, the rate k_1, and its components k_{S_N1} and k_{E1}, will in general vary largely from one compound RX to another; in particular they will vary when, with a constant alkyl group R, we modify X. But the proportion in which the first-order reaction follows a particular path, *i.e.*, the ratio k_{E1}/k_1, should depend essentially on R, and not on X. This statement represents only a first approximation, and is too sweeping to be quite accurate: for, as our stereochemical studies have shown, X may be only a few atomic diameters away when the fate of R is determined, and therefore the nature of X may have some small influence on the result. We know that, when, in unimolecular hydrolysis, the dissociation of RX has passed over its energy barrier, the receding X^- still shields R^+ sufficiently to cause a disparity between the rates at which R^+ is attacked from the two sides: there is incomplete racemisation. Therefore X^- may be expected, at the same stage of dissociation, to have an appreciable influence on the relative rates at which R^+ suffers attack in the two possible locations, *viz.*, at the cationic carbon atom and at the β-hydrogen atom. However, this effect would be expected to create only minor variations in the ratio of velocities, and should certainly not affect its order of magnitude; whereas by changing X we might well change even the orders of magnitude of the velocities themselves. On passing from β-*n*-octyl chloride to the bromide the value of k_1 is in fact increased 33-fold, and k_{S_N1} and k_{E1} are increased similarly; but the ratio k_{E1}/k_1 is scarcely altered by 10%. The values for 100° are as follows:

	10^5k_1.	$10^5k_{S_N1}$.	10^5k_{E1}.	k_{E1}/k_1.
β-*n*-Octyl chloride	0·805 sec.$^{-1}$	0·700 sec.$^{-1}$	0·105 sec.$^{-1}$	0·13
β-*n*-Octyl bromide	26·8 ,,	23·0 ,,	3·75 ,,	0·14

Some further applications of this principle are given in the following papers, and the results are uniformly in favour of the unimolecular mechanisms suggested.

EXPERIMENTAL.

Methods.—An approximately $N/10$-solution containing an accurately known weight of β-*n*-octyl chloride or bromide in an aqueous alcohol prepared from 8 vols. of anhydrous ethyl alcohol and 2 vols. of water was made up; and 5 c.c. portions of this were enclosed, each with a 5 c.c. portion of an aqueous alcohol made from 4 vols. of dry ethyl alcohol and 6 vols. of water, in a series of bulbs, which were warmed and shaken until the contents were homogeneous, and then heated at 80° or 100° for the required length of time. Each bulb was then crushed under 100 c.c. of carbon tetrachloride, and the solution thus obtained was washed with water, and treated for 0·5 hour with a standard solution of bromine, the excess of which was then titrated with $N/50$-thiosulphate. A blank experiment conducted in the same way, but without giving opportunity for the development of olefin, served to standardise the bromine solution.

Results.—These are given in the introduction, but we add some illustrative details. The following record represents a determination (Expt. 171) of the progress of olefin development from β-*n*-octyl chloride in 60% aqueous ethyl alcohol at 100°. The original concentration of chloride in this experiment was 0·0570*M*. Samples of 10 c.c. were used for each estimation of olefin, and the quantity of this found is expressed as its equivalent in c.c. of $N/50$-thiosulphate solution:

Time (hours)	6·0	15·0	22·0	28·0	46·0	∞
Olefin (c.c. of $Na_2S_2O_3$)	1·37	3·12	3·72	3·97	5·24	7·37

The graphically determined rate constant agrees with the mean value given previously. For the chloride at 100° the constants k_1 ranged from $0·99 \times 10^{-5}$ (an isolated high value) to $0·77 \times 10^{-5}$ sec.$^{-1}$; for the bromide at 80° only a single determination was made, and for the bromide at 100° two determinations, which gave $25·5 \times 10^{-5}$ and $28·1 \times 10^{-5}$ sec.$^{-1}$. It will be appreciated that, since the proportion of the total decomposition which yields olefin is constant throughout the unimolecular reaction, the rate constants calculated in the usual way from the slopes of the logarithmic plots of the olefin estimations represent k_1 and not k_{E1}. In order to obtain k_{E1} it is necessary to determine the proportion of the total decomposition which results

in olefin, and separate estimates of this quantity gave the following results, the solvent being in all cases 60% aqueous ethyl alcohol.

β-*n*-Octyl bromide at 80°	9·12	9·49	9·59	10·60%
β-*n*-Octyl chloride at 100°	13·1	13·4	12·6	12·7%
β-*n*-Octyl bromide at 100°	14·0	14·1	14·0%	

The means of these figures are quoted in the introduction.

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260. *The Mechanism of Elimination Reactions. Part III. Unimolecular Olefin Formation from* tert.*-Butyl Halides in Acid and Alkaline Aqueous Solutions.*

By KENNETH A. COOPER, EDWARD D. HUGHES, and CHRISTOPHER K. INGOLD.

The search for unimolecular elimination as an accompaniment of aqueous hydrolysis (this vol., p. 1277) is here extended to *tert.*-butyl chloride, bromide and iodide. The reaction is again found, and its kinetic properties demonstrated.

The prediction that the rates of the unimolecular substitution and elimination should change by much larger factors than their ratio when we pass from one halide to another is again confirmed. From chloride to iodide the individual rates increase by about 100-fold, whilst their ratios remain constant to a factor of 1·3.

As Hughes first showed (J., 1935, 255), the hydrolysis of *tert.*-butyl chloride in aqueous solvents is exclusively unimolecular, even in the presence of alkaline hydroxides; and this result has been generalised by Cooper and Hughes for the other *tert.*-butyl halides (this vol., p. 1183). Since these results indicate that the *tert.*-butyl cation is readily formed, it was of interest to determine whether it would show any tendency, in the presence of the competing attack of a reactive solvent, to break down in the manner which results in the unimolecular production of olefin.

The first point to be determined was whether under any conditions olefin would be formed in sufficient amount for kinetic investigation from *tert.*-butyl halides in aqueous solvents. To our surprise we found that olefin was produced in considerable quantity: the literature had suggested otherwise. In a chemical examination of the products of a completed hydrolysis of *tert.*-butyl chloride Hughes found no olefin (*loc. cit.*); and French, McShan, and Johler, working with *tert.*-butyl bromide in a heterogeneous system, recorded a maximal yield of 2% of olefin (*J. Amer. Chem. Soc.*, 1934, **56**, 1346). We now know that there is no inconsistency between these statements and our present finding that about 10—20% of olefin may be formed from these halides: the fact is that under many conditions the olefin, after having been formed comparatively rapidly, disappears again slowly on account of hydration: so that an examination of the products of a "completed" reaction may fail to reveal olefin, or anything like as much of it as has been present; and in order to prove its formation one must follow the variation of its concentration with time from the commencement of the experiment.

We do not elaborate this matter of the eventual disappearance of olefin in the present paper, partly because it is considered more fully in the next paper, which deals with the homologous *tert.*-amyl halides; and partly because, by employing suitable conditions, we were able to study the formation of olefin without serious interference from the subsequent hydration. We show, however, that this hydration of the olefin depends on the development of acidity in the solution, and does not take place in an alkaline medium.

For the study of olefin production we found it convenient generally to employ "80%" aqueous ethyl alcohol as solvent, and the temperature 25°; although some of the experiments on olefin disappearance were, for greater expedition, carried out at 50°.

The occurrence of unimolecular hydrolysis (S_N1) opens up the possibility of unimolecular elimination (E1) for reasons given; but the absence of bimolecular hydrolysis (S_N2), even in alkaline solution, does not imply the exclusion of the independent bimolecular elimination

(E2). We established in the example of *tert.*-butyl bromide that in the presence of a considerable concentration of alkali hydroxide an appreciable part of the olefin-forming process is dependent on the alkali: this part is possibly the bimolecular elimination (E2), although we were unable to isolate it kinetically. The main olefin-producing reaction of both *tert.*-butyl chloride and bromide under all the conditions investigated proceeded by the unimolecular mechanism (E1); its rate was unaffected either by dilute alkali or by acid, and accurately followed the first-order equation. There can be no doubt that olefin formation from *tert.*-butyl iodide is likewise essentially unimolecular, although this halide was not studied in such detail as the others.

The rate of the total reaction, hydrolysis plus elimination ($k_1 = k_{S_N1} + k_{E1}$), is interpreted as the rate of formation of the *tert.*-butyl cation. This rate increases in the order chloride < bromide < iodide, by a factor of 44 for the first two, and $2\frac{1}{2}$ for the last two of these halides, for the same solvent and temperature. The ratio of the rate of olefin formation to that of the total reaction for any halide is interpreted as measuring the proportion in which the cation partitions itself between alternative modes of decomposition. Under corresponding conditions, this ratio extends over the range 0·13—0·17 for the same three halides. The figures are as follows:

	$10^5 k_1$.	$10^5 k_{S_N1}$.	$10^5 k_{E1}$.	k_{E1}/k_1.
tert.-Butyl chloride	0·854 sec.$^{-1}$	0·710 sec.$^{-1}$	0·144 sec.$^{-1}$	0·168
,, bromide	37·2 ,,	32·5 ,,	4·69 ,,	0·126
,, iodide	90·1 * ,,	78·5 ,,	11·6 ,,	0·129

* Cooper and Hughes, *loc. cit.*

The comparatively small variation in the ratio is consistent with the view that the hydrolysis and elimination have a common slow stage (preceding paper).

Experimental.

Methods.—The " 80% " aqueous ethyl alcohol used in these experiments was part of a batch employed by Cooper and Hughes (*loc. cit.*), so that our rates at 25° should be directly comparable with theirs. The " 80% " alcohol used at an earlier date by Hughes (*loc. cit.*) gave rates about 7% greater, and was presumably very slightly more aqueous (a difference of composition amounting to a small fraction of 1% would account for this difference of rate).

The runs were followed by enclosing samples of the original solution in sealed bulbs, which eventually were broken under carbon tetrachloride, the olefin being extracted with this solvent, and estimated bromometrically as described in the preceding paper. In order to eliminate error due to the formation of olefin before the mixtures, which were sealed up at 0°, had reached the temperature of the thermostat, an " initial " estimation of olefin was made on a sample which had been shaken in the thermostat for one minute. The samples used for the other estimations were similarly shaken in the thermostat for one minute, the end of which was taken as the zero of time.

Because the total reaction and its separate constituents are all of the first order, the constants calculated from the expression $(2{\cdot}303/t).\log_{10}\{(x_\infty - x_0)/(x_t - x_0)\}$, where the x's represent olefin concentrations, are rate-constants (k_1) of the total reaction, and not those (k_{E1}) of the partial reaction which actually is being followed analytically. In order to obtain the latter rate-constant we must multiply the former by the proportion of olefin formed. For the purpose of measuring this proportion it is necessary to know something about the rate of disappearance of olefin, in order to ensure that the measurement is not disturbed by this phenomenon.

tert.-*Butyl Chloride.*—Solvent " 80% " aqueous ethyl alcohol throughout.

(Expt. 1). Temp. 25°. Solution originally neutral. Chloride originally about 0·091*M*. Olefin concentrations, x, expressed in c.c. of 1·050*N*/20-thiosulphate per 20 c.c. sample.

t (hours) ...	0·00	6·95	10·00	15·13	21·0	27·0	33·0	" ∞ "
x (c.c.)	1·45	4·54	5·13	6·98	8·20	9·69	11·26	16·06
k_1 (hr.$^{-1}$) ...	—	0·0342	0·0290	0·0317	0·0295	0·0308	0·0337	Mean: 0·0315

(Expt. 2). Temp. 25°. Solution originally 0·10*N* with respect to sodium hydroxide and about 0·091*M* with respect to chloride. Olefin concentrations in c.c. of 0·9745*N*/20-thiosulphate per 20 c.c. sample.

t (hours)	0·00	6·95	10·02	15·58	21·10	27·85	32·4	49·1	" ∞ "
x (c.c.) ...	0·64	3·05	4·10	6·04	7·05	8·58	9·21	11·43	14·56
k_1 (hr.$^{-1}$)...	—	0·0274	0·0284	0·0316	0·0293	0·0320	0·0295	0·0320	Mean: 0·0300

Summary. Mean k_1 from expts. 1 and 2 = 0·0307 hour^{-1} = 0·854 × 10^{-5} sec.$^{-1}$. The value obtained by Hughes (*loc. cit.*) by direct measurement of the total reaction was 0·914 × 10^{-5} sec.$^{-1}$ (see below).

(Expt. 3). Temp. 25°. Solution originally neutral. Chloride originally 0·182*M*. Olefin concentrations in c.c. of 0·9745*N*/20-thiosulphate per 20 c.c. sample. Series of "infinity" values :

t (hours)	120	128	148	168	
x (c.c.)	23·89	23·19	23·72	23·51	Mean : 23·58

(Expt. 4). Temp. 25°. Solution originally neutral. Chloride originally 0·182*M*. Olefin concentrations in c.c. of 0·983*N*/20-thiosulphate per 20 c.c. sample. "Infinity" values showing incursion of the olefin hydration :

t (hours.)	160	164	168	240	504
x (c.c.)	24·79	24·34	24·04	22·22	17·73

(Expt. 5). Temp. 25°. Solution originally neutral. Chloride originally 0·182*M*. Olefin concentrations, *x*, in c.c. of 0·986*N*/20-thiosulphate, and acidity, *y*, in c.c. of 1·020*N*/10-alkali, each per 20 c.c. sample. "Infinity" values showing incursion of olefin hydration (*x* finally falls, whilst *y* remains constant) :

t (hours)	22·6	44·6	71·0	92·3	113·1	160·0	185·0	210·0	240·5
x (c.c.)	13·4	19·44	23·78	25·56	26·86	26·27	25·71	23·7	22·0
y (c.c.)	18·39	—	31·70	33·51	34·17	—	35·25	35·16	34·94

Summary. Proportion of olefin from x_∞ values of expts. 3—5 : (3) 0·158, (4) 0·167, (5) 0·180. Mean : 0·168.

(Expt. 6). Temp. 50°. Solution originally neutral. Chloride originally 0·182*M*. Olefin concentrations, *x*, expressed in c.c. of 0·986*N*/20-thiosulphate per 20 c.c. sample. Acidity, *y*, expressed in c.c. of 1·020*N*/20-alkali. Series showing the incursion of olefin hydration (*x* finally falls, whilst *y* remains constant) :

t (hours)	0·00	0·32	1·02	2·00	5·20	22·0	47·5	72·4	146·1
x (c.c.)	0·30	7·32	19·26	27·46	31·80	19·52	10·92	6·51	2·28
y (c.c.)	0·33	6·70	19·58	27·70	34·62	—	35·09	35·20	34·56

(Expt. 7). Temp. 50°. Solution originally 0·240*N* with respect to sodium hydroxide. Chloride originally 0·182*M*. Olefin concentrations, *x*, expressed in c.c. of 0·986*N*/20-thiosulphate and alkalinity, *z*, in c.c. of 0·960*N*/20-acid, each per 10 c.c. sample. Series showing the absence of olefin hydration in alkaline solution.

t (hours)	5·30	25·75	72·3	149·0
x (c.c.)	19·34	19·58	19·46	19·39
z (c.c.)	14·80	13·45	12·72	—

The slow diminution in the value of *z* probably represents attack by the alkali on the glass of the sealed vessels.

tert.-*Butyl Bromide*.—Solvent : "80%" aqueous ethyl alcohol; temp. 25°, throughout.

(Expt. 11). Solution originally neutral. Bromide originally 0·0865*M*. Olefin concentrations, *x*, expressed in c.c. of 0·9745*N*/20-thiosulphate per 20 c.c. sample.

						∞		
t (min.)	0·0	10·0	45·0	72·0				
x (c.c.)	1·75	3·09	6·03	7·49	8·62	8·87	8·51	Mean : 8·67
k_1 (min.$^{-1}$)	—	0·0215	0·0214	0·0245	Mean : 0·0225 = 37·5 × 10^{-5} sec.$^{-1}$			

The "infinity" analyses were made between 10 and 20 hours from the commencement of reaction. Olefin hydration remains inappreciable for the first 50 hours (see expt. 15).

(Expt. 12). Solution originally neutral. Bromide originally 0·173*M*. Olefin concentrations expressed in c.c. of 0·9745*N*/10-thiosulphate per 20 c.c. sample.

t (min.)	0·0	10·0	24·5	41·1	74·0	"∞"
x (c.c.)	0·00	1·74	3·67	5·73	7·42	9·18
k_1 (min.$^{-1}$)	—	0·0210	0·0208	0·0239	0·0244	Mean : 0·0220 = 36·7 × 10^{-5} sec.$^{-1}$

(Expt. 13). Solution originally neutral. Bromide originally 0·173*M*. Olefin concentration expressed in c.c. of 0·9745*N*/20-thiosulphate per 20 c.c. sample.

t (min.)	0·0	10·1	23·5	42·7	73·1	"∞"
x (c.c.)	1·66	5·20	8·30	11·73	14·44	18·00
k_1 (min.$^{-1}$)	—	0·0242	0·0222	0·0224	0·0209	Mean : 0·0224 = 37·3 × 10^{-5} sec.$^{-1}$

Summary. Mean k_1 from expts. 11—13 : 37·2 × 10^{-5} sec.$^{-1}$. Value obtained by direct measurement of the total reaction (Cooper and Hughes) : 37·4 × 10^{-5} sec.$^{-1}$.

(Expt. 14). Solution originally neutral. Bromide originally 0·173*M*. Olefin concentrations in c.c. of 0·983*N*/20-thiosulphate per 20 c.c. sample. Series of " infinity " determinations prior to appreciable olefin hydration.

t (hours)	16	18	20	22	24	
x (c.c.)	17·46	18·27	18·23	17·05	17·24	Mean : 17·65

(Expt. 15). Solution originally neutral. Bromide originally 0·173*M*. Olefin concentrations in c.c. of 0·983*N*/20- or 0·986*N*/20-thiosulphate (*A* or *B* respectively). Readings made with *B* are converted for comparison into terms of *A*. Some values of x_∞ are calculated from measured values of x_t by dividing by the proportion in which the total decomposition of the halide, as determined by measurement of acidity, is incomplete. The purpose of the run is to measure x_∞, and illustrate the incursion of olefin hydration.

t (hours)	0·00	1·23	3·0	10·7	16·6	57·2	91·5	140·5	312·0
x { c.c. *A*	2·74	14·00	17·02	—	—	17·94	—	—	—
x { c.c. *B*	—	—	—	17·25	17·40	—	16·38	15·88	13·45
% Acidity	—	80·0	98·0	100·0	100·0	100·0	100·0	100·0	100·0
x_∞, c.c. *A*	—	17·50	17·36	17·31	17·46	17·94	16·44	15·94	13·49

Mean of 1st five x_∞ values = 17·51 c.c.

(Expt. 16). Solution originally 0·255*N* with respect to potassium hydroxide and 0·173*M* with respect to bromide. *Olefin concentrations in c.c. of 0·983N/20-thiosulphate for 20 c.c.* sample.

t (hours)	16	18	22	24	
x (c.c.)	25·58	25·57	25·60	26·24	Mean : 25·75

Summary. Proportion of olefin from x_∞ values of expts. 11—15 : (11) 0·122, (12) 0·129, (13) 0·127, (14) 0·125, (15) 0·125. Mean : 0·126.

tert.-*Butyl Iodide.*—Solvent " 80% " aqueous ethyl alcohol. Temp. 25° throughout. Accurate time-runs could not be carried out because bromine attacks *tert.*-butyl iodide liberating iodine, thus creating errors of the order of 10% in the estimates of olefin made by the bromination method. Direct estimates of x_∞ are not subject to this error, because *tert.*-butyl iodide is absent from the samples analysed.

(Expt. 21). Solution originally neutral and 0·165*M* with respect to iodide. Olefin concentrations expressed (below) in c.c. of 1·050*N*/20-thiosulphate per 20 c.c. sample.

(Expt. 22). Solution originally neutral and 0·0825*M* with respect to iodide. Olefin concentrations expressed as above.

	Expt. 21.				Expt. 22.		
t (hours)	16	20	24	Mean	16	24	Mean
x (c.c.)	16·04	13·37	17·44	15·6	7·89	7·97	7·93

Summary. Proportions of olefin from x_∞ values of expts. 21 and 22 : (21) 0·129, (22) 0·131. Mean : 0·130.

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261. *The Mechanism of Elimination Reactions. Part IV. Unimolecular Olefin Formation from* tert.-*Amyl Halides in Acid and Alkaline Aqueous Solutions, and Some Remarks on the Scope of the Unimolecular Mechanism.*

By EDWARD D. HUGHES and BASIL J. MACNULTY.

tert.-Amyl chloride, bromide and iodide exhibit unimolecular substitution (this vol., p. 1177) and unimolecular elimination (this vol., p. 1271) in hydrolysis, and present cases particularly favourable to quantitative investigation of the unimolecular elimination. The kinetic properties of the simultaneous reactions of the halides are investigated.

The rate constants of the *tert.*-amyl halides are all higher than those of the corre-

sponding *tert.*-butyl halides (preceding paper), and increasing alkylation leads to *an increasing preference for the elimination reaction*. For a given halogen atom, the change of alkyl groups alters the ratio of the rates of substitution and elimination by a factor of the same order as that which measures the alteration in the individual rates; whereas the change of the halogen atom may alter the order of magnitude of the rates, but, for a given alkyl group, leaves the rate-ratio almost unchanged. The results support the hypothesis that the division of the reaction between substitution and elimination occurs essentially after the separation of the alkyl group from the halogen atom (cf. preceding papers).

In acid solution equilibria are set up subsequently to the original hydrolysis: the olefin becomes hydrated and the alcohol dehydrated by reactions which are considered to be specialised forms of the substitution and elimination processes herein discussed. Some further cases of unimolecular elimination are cited.

A SURVEY of the literature having shown that the hydrolysis of *tert.*-amyl halides, even under conditions expected to lead to first-order kinetics, involves much olefin elimination, it appeared that a kinetic study of these reactions would be of assistance in the elucidation of the mechanism of elimination, and provide a specially favourable case in which to test the theory of a common slow stage in unimolecular elimination and substitution (see Parts II and III). Furthermore, since the rates of the unimolecular hydrolysis and elimination reactions of the *tert.*-butyl halides are known (Hughes, J., 1935, 255; Cooper and Hughes, this vol., p. 1183; Cooper, Hughes, and Ingold, this vol., p. 1280), the study of the *tert.*-amyl halides must show the effect of increased alkylation on the rates of these reactions. Yet another motive for the present work was our desire to prepare the ground for an investigation into the preferential elimination of isomeric olefins from a branched-chain hydrocarbon radical, and for this also the *tert.*-amyl halides commended themselves.

It is well known that the *tert.*-amyl halides hydrolyse easily, and that *tert.*-amyl alcohol and unsaturated hydrocarbons may, under certain conditions, be isolated from the products. Thus the hydrolysis of the iodide with cold water is said to give *tert.*-amyl alcohol (Bauer, *Annalen*, 1883, **220**, 158), while a mixture of trimethylethylene and *as.*-methylethylethylene is reported to be obtainable with the agency of hot alcoholic potassium hydroxide (Wagner, *Ber.*, 1888, **21**, 1230; Kondakoff, *J. pr. Chem.*, 1896, **54**, 442; *J. Russ. Phys. Chem. Soc.*, 1889, **21**, 78; and others). Recently, Woodburn and Whitmore (*J. Amer. Chem. Soc.*, 1934, **56**, 1394) treated *tert.*-amyl chloride and bromide with water and with acidic and basic reagents, and obtained varying proportions of *tert.*-amyl alcohol and trimethylethylene, depending on the conditions used. In the case of the chloride it was shown that the hydrolysis proceeded with almost the same velocity whether the reagent was dilute sodium carbonate, water, or dilute sulphuric acid. Two liquid phases were present in these experiments; nevertheless the results mentioned indicate that the total decomposition is of the first order, its speed being independent of reagent anions; and this must be true for the formation of both alcohol and olefin, since each is produced in large amount. French and Schaefer (*J. Amer. Chem. Soc.*, 1935, **57**, 1576) determined the proportions of olefin formed when *tert.*-amyl chloride and bromide were stirred heterogeneously at 35° and 45° with aqueous solutions of barium hydroxide (0·20—0·25*M*), and concluded that an increase in the concentration of the base results in an increase in the percentage of olefin. It is significant, however, that if we omit from consideration their experiments with silver oxide, where a different mechanism is operative (cf. this vol., pp. 1237, 1243, 1252), approximately the same amount of olefin was obtained with all the reagents they used; it was the same, for instance, with a sparingly soluble base like calcium hydroxide as with sodium hydroxide.

All our measurements were made in homogeneous solution; and, with the exception of olefin formation in the hydrolysis of *tert.*-amyl iodide, they include a kinetic investigation of both the total reaction and the olefin elimination for the chloride, bromide, and iodide, in acid and in alkaline solution. Most of the measurements were carried out in 80% alcohol at 25°, but, in the case of the chloride, experiments were also made at 50° and in 60% alcohol. The results are summarised in Table I. The headings of the first three cols. are self-explanatory. Cols. 4 and 5 give the initial concentrations of the reagents specified. Col. 6 records the average first-order velocity coefficient (k_1) for the total reaction in sec.$^{-1}$,

and cols. 7 and 8 give the analogous coefficients for the constituent processes of elimination (k_{E1}) and substitution (k_{S_N1}) in the same units; k_1 and k_{E1} were determined separately, and k_{S_N1} was obtained by difference. The last col. gives the ratio of the elimination reaction to the total decomposition.

TABLE I.

Summary of the First-order Rate Constants of the Hydrolysis of the tert.-*Amyl Halides.*

Expt.	Halide.	Medium.	Temp.	[Halide].	[NaOH].	10^5k_1.	10^5k_{E1}.	$10^5k_{S_N1}$.	k_{E1}/k_1.
1	Am$^{\gamma}$Cl	80% aq.-alc.	25·2°	0·161	—	1·40	0·459	0·941	0·328
2	,,	,,	,,	0·0787	—	1·50	0·500	1·00	0·333
3	,,		,,	0·0776	0·212	1·52	0·515	1·01	0·339
4	,,		50·0	0·1471	—	28·5	11·5	17·0	0·403
5	,,	60% aq.-alc.	25·2	0·0783	—	14·8	3·81	11·0	0·257
6	Am$^{\gamma}$Br	80% aq.-alc.	,,	0·0722	—	58·3	15·3	43·0	0·262
7	,,	,,	,,	0·0654	0·118	58·0	17·9	40·1	0·308
8	Am$^{\gamma}$I	,,	,,	*ca.* 0·13	—	174	45·2	128·8	0·260
9	,,	,,	,,	*ca.* 0·12	0·12	178	43·8	134·2	0·246

The unimolecular nature of both the total reaction and the elimination was proved for the chloride by the constancy of the first-order rate coefficients, and by the ineffectiveness of alkali. The slight differences in the velocity constants recorded in experiments 1 and 2 are undoubtedly to be attributed to a medium effect (cf. Hughes, *loc. cit.*). Similar, but less extended, tests established the unimolecular nature of the reactions of the bromide and the iodide. The slight effect of alkali on the velocity of the elimination reaction of the bromide appears to be connected with the ratio in which the total decomposition is divided between substitution and elimination, and not with the incursion of a second-order elimination process. This is indicated by the fact that the rate of the total reaction is not altered by the alkali.

Our results indicate how physical conditions control the proportions in which the alkyl halide undergoes elimination and substitution *: measurements on *tert.*-amyl chloride were carried out at two temperatures and in two aqueous-alcoholic media of different water content, and the results showed that olefin elimination is favoured relatively to the substitution by an increase in temperature and by a low water content in the medium.

We compare in Table II the rate constants for the *tert.*-amyl halides with those obtained for the *tert.*-butyl halides under similar conditions (previous paper). The medium in each case was 80% alcohol and the temperature was 25·0° for the *tert.*-butyl halides and 25·2° for the *tert.*-amyl halides. The first-order constants are in sec.$^{-1}$.

TABLE II.

First-order Rate Constants of the Hydrolysis of the tert.-*Butyl and* tert.-*Amyl Halides.*

	tert.-Butyl halides.				*tert.*-Amyl halides.			
	10^5k_1.	10^5k_{E1}.	$10^5k_{S_N1}$.	k_{E1}/k_1.	10^5k_1.	10^5k_{E1}.	$10^5k_{S_N1}$.	k_{E1}/k_1.
Chloride	0·854	0·144	0·710	0·168	1·50	0·50	1·00	0·333
Bromide	37·2	4·69	32·5	0·126	58·3	15·3	43·0	0·262
Iodide	90·1	11·6	78·5	0·129	174	45·2	128·8	0·260

Several interesting relationships emerge from this comparison. First, in each alkyl series there are much larger velocity differences between chloride and bromide than between bromide and iodide, and this is true of all the velocity coefficients recorded. This phenomenon appears to be general and has already been discussed for the reactions of the *iso*propyl halides, and the total reaction of the *tert.*-butyl halides (Hughes and Shapiro, this vol., p. 1177; Cooper and Hughes, this vol., p. 1183). Secondly, the rate constants for the *tert.*-amyl halides are all larger than the corresponding constants for the *tert.*-butyl halides. The reaction is obviously one which is facilitated by electron release to the halogen atom, and in this example the inductive effect of the additional methyl group present in the *tert.*-amyl halides outweighs any effect of opposite kind such as that postulated by Baker and Nathan (J., 1935, 1844). The apparently much smaller reactivity

* The substitution is composite in that both *tert.*-amyl alcohol and ethyl *tert.*-amyl ether are formed in aqueous ethyl alcohol.

of *tert.*-amyl than of *tert.*-butyl chloride, observed by Woodburn and Whitmore (*loc. cit.*) in their experiments in heterogeneous solution, must, as these authors suggest, be due to the smaller solubility of the higher homologue in the aqueous phase; the apparent stability of *tert.*-amyl chloride in heterogeneous hydrolysis was also observed by French and Schaefer (*loc. cit.*). Thirdly, the ratios k_{E1}/k_1 are approximately twice as great for the *tert.*-amyl halides as for the *tert.*-butyl compounds, so that increasing alkylation evidently leads to an increasing preference for the elimination reaction. This fact is of importance in relation to the question of the preferential elimination of isomeric olefins from branched-chain hydrocarbon radicals, a question which is being investigated.

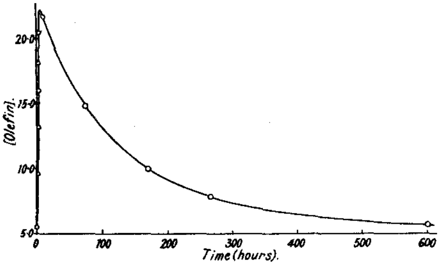
The relative constancy in the k_{E1}/k_1 ratios exhibited by different halides containing a common alkyl radical, already pointed out for the *sec.*-octyl and *tert.*-butyl halides, is again shown by the *tert.*-amyl halides. Table II brings into contrast the effects obtained by changing the alkyl group and the halogen atom. When we change the alkyl group from *tert.*-butyl to *tert.*-amyl the individual rates change by factors of $1\frac{1}{2}$—4, and the k_{E1}/k_1 ratio by a factor of 2: the change in the ratio is of the same order as the change in the rates. When however, in either alkyl series, we replace chlorine by bromine or iodine the rates change by factors of 30—130, and yet the k_{E1}/k_1 ratio remains constant to within a factor of 1·3. This contrast forms strong support for the hypothesis that the division of the reaction between substitution and elimination occurs essentially after the separation of the alkyl group from the halogen atom (cf. Parts II and III).

A complication arose in the experiments in acidic solutions owing to the disappearance of a portion of the olefin. No such disturbance was encountered in any of the experiments in alkaline solution, and there is little doubt that it is due to acid-catalysed hydration of the hydrocarbon. This reaction is well established: it was studied by Butlerow in his experiments on *iso*butylene and trimethylethylene (*Annalen*, 1867, **144**, 34; 1877, **189**, 44), and a kinetic investigation has recently been carried out by Lucas and his collaborators (Lucas and Eberz, *J. Amer. Chem. Soc.*, 1934, **56**, 460, 1230; Lucas and Liu, *ibid.*, p. 2138). These authors concluded that the reaction was of the first order with respect to both the olefin and the acid, and in the case of *iso*butylene was measurably reversible. One would expect that the disappearance of the olefin in acidic media is likely to disturb the observation of its formation from the halide most seriously when the concentration of the latter is low and that of the hydrocarbon and of the acid is high, *i.e.*, towards the end of hydrolysis; and this has been our experience. The greatest interference was experienced in the hydrolysis of the chloride in 80% aqueous ethyl alcohol at 25·2°; but even in this case only the second half of the reaction was noticeably affected, and the difficulty could be overcome (cf. p. 1289). In the hydrolysis of the chloride in 80% alcohol at 50°, and in 60% alcohol at 25°, the disturbance became appreciable only towards the end of the reaction. The hydrolysis of the bromide and the iodide, being much faster than that of the chloride, was not affected, although the hydration was observed after the initial reaction had completed its course. Our results also establish the reversibility of the hydration, although, on account of its extreme slowness in the ultimate stages, we cannot say with certainty that equilibrium was reached in any of our experiments. This is illustrated in the annexed plot of olefin concentration against time. The steep ascending portion of the curve represents the formation of olefin from the halide, and the descending portion, which becomes asymptotically parallel to, but displaced from, the time-axis, represents the reversible hydration of the hydrocarbon.

The reactions here exemplified may be interpreted as follows. The initial process is the ionisation of the halide, and the hydrocarbon cation either unites with an anion or loses a proton. These are the unimolecular substitution and elimination reactions of the halide (S_N1 and E1). The total reaction is of the first order (R = Alk. or H):

$$\left.\begin{array}{l} CR_2H\cdot CR_2\cdot Hal. \xrightarrow{\text{slow}} CR_2H\cdot CR_2^+ + Hal.^- \\ CR_2H\cdot CR_2^+ \begin{cases} \xrightarrow{\text{fast}} CR_2H\cdot CR_2\cdot OH \quad (S_N1) \\ \xrightarrow{\text{fast}} CR_2{:}CR_2 + H^+ \quad (E1) \end{cases} \end{array}\right\} \quad . \quad . \quad . \quad . \quad (1)$$

In alkaline solution this is all that happens. In acid solution, however, each of the two products undergoes further change dependent on proton transfer. First, the alcohol forms an oxonium ion, and then undergoes slow ionisation, analogously to the chloride, with



Illustrating the formation of olefin in the hydrolysis of tert.*-amyl chloride, and its subsequent hydration. Solvent : 80% aqueous ethyl alcohol. Temp.* 50·0°. *Initially* [AmᵞCl] = 0·1471*N and solution neutral.* [*Olefin*] *expressed in equivalent c.c. of* 0·04904*N*-$Na_2S_2O_3$ *per* 10 *c.c. of solution.*

resulting unimolecular substitution and elimination (S_N1 and E1). The total reaction is of the second order, being of the first with respect to hydrogen ions and the first with respect to alcohol :

$$\left.\begin{array}{l} CR_2H{\cdot}CR_2{\cdot}OH + H^+ \underset{}{\overset{\text{fast}}{\rightleftharpoons}} CR_2H{\cdot}CR_2{\cdot}OH_2^+ \\ CR_2H{\cdot}CR_2{\cdot}OH_2^+ \xrightarrow{\text{slow}} CR_2H{\cdot}CR_2^+ \\ CR_2H{\cdot}CR_2^+ \begin{cases} \xrightarrow{\text{fast}} CR_2H{\cdot}CR_2{\cdot}OH & (S_N1) \\ \xrightarrow{\text{fast}} CR_2{:}CR_2 + H^+ & (E1) \end{cases} \end{array}\right\} \quad . \quad . \quad . \quad . \quad (2)$$

Unimolecular substitutions in 'onium salts are well established (Hughes and Ingold, J., 1933, 69, 1571; 1935, 244; Hughes, Ingold and Patel, J., 1933, 526; Gleave, Hughes and Ingold, J., 1935, 236). The one here represented is not ordinarily observable, but it amounts to an acid-catalysed exchange of hydroxyl between the alcohol and water, and is being studied in these laboratories with the aid of heavy-oxygen water. Unimolecular elimination has not yet been kinetically established for 'onium salts generally,* but the extension of the work on the halides will include its study.

Secondly, the olefin forms a hydrocarbon cation, which then decomposes in the same two ways. This reaction is of the second order, being of the first order with respect to hydrogen ions and the first order with respect to olefin :

$$\left.\begin{array}{l} CR_2{:}CR_2 + H^+ \xrightarrow{\text{slow}} CR_2H{\cdot}CR_2^+ \\ CR_2H{\cdot}CR_2^+ \begin{cases} \xrightarrow{\text{fast}} CR_2H{\cdot}CR_2{\cdot}OH & (S_N1) \\ \xrightarrow{\text{fast}} CR_2{:}CR_2 & (E1) \end{cases} \end{array}\right\} \quad . \quad . \quad . \quad . \quad (3)$$

The first reaction is a hydration, and the second, not ordinarily observable, could be investigated (if one of the groups written as R were hydrogen) with the aid of deuterium as an acid-catalysed hydrogen-exchange. In acid solution, then, the reaction systems (2) and (3) operate in addition to (1); indeed, (1) and (2) supply the olefin required for (3), whilst (1) and (3) provide the alcohol necessary for (2). A consideration of these schemes, and a knowledge of the ratio in which the cation partitions itself between substitution and elimination, should form an adequate guide in predicting the course of hydrolysis under given circumstances. The general result will always be that in the first phase of reaction halide

* We include in this category the acid-catalysed decomposition of certain ethers.

disappears and alcohol and olefin are formed. The proportion in which they are formed will, however, be determined by the cation partition ratio, and will not be the equilibrium proportion. In acid solution a second phase of reaction supervenes and in this the alcohol and olefin come into equilibrium. In the figure the rising branch of the curve shows the formation of olefin in the first phase (reactions 1), whilst the falling branch illustrates the equilibration of olefin with alcohol during the second phase (reactions 2 and 3).

As an example we may consider a statement by Woodburn and Whitmore (*loc. cit.*): "The hydrolysis of tertiary chlorides with hot water or sodium carbonate solution gives olefin exclusively. With *cold* water or *cold* sodium hydroxide solution, a certain amount of tertiary alcohol is formed with the olefin." In alkaline solution the only reactions are the irreversible processes (1), and, in view of the olefin/alcohol ratios exhibited by the *tert.*-butyl and the *tert.*-amyl chlorides, the remark concerning sodium carbonate cannot be generally true. In the absence of alkali, the production of acid brings in reactions 2 and 3, which would set up an equilibrium between the alcohol and the olefin, and the validity of the statement relating to the effect of hot water would appear to depend on the possible circumstance that the olefin, being volatile in the *hot* water, may be removed as it is formed, and thus produced quantitatively.

A probable example of unimolecular elimination and substitution, which involves neither a halide nor an 'onium compound but the ester of a strong acid, is the etherification of ethyl alcohol in the presence of sulphuric acid. We suppose that the ethyl hydrogen sulphate ionises; and that the cation, in the presence of alcohol, gives ether; otherwise it gives ethylene:

$$C_2H_5{\cdot}O{\cdot}SO_3H \xrightarrow{\text{slow}} C_2H_5^+ + O{\cdot}SO_3H^-$$

$$C_2H_5^+\begin{cases}\xrightarrow{\text{fast}} C_2H_5{\cdot}OC_2H_5 & (S_N1)\\ \xrightarrow{\text{fast}} C_2H_4 & (E1)\end{cases}$$

It may be noted in this connexion that the $\cdot SO_3R$ group has so great a tendency to ionise that unimolecular processes are expected, not only for secondary and tertiary alkyl esters, but also for ethyl, and even the methyl, compounds.

EXPERIMENTAL.

tert.-*Amyl Halides.*—The products obtained by shaking *tert.*-amyl alcohol with the concentrated halogen acids were saturated with the gaseous hydrogen halide, and distilled from anhydrous potassium carbonate.

Media.—Commercial absolute ethyl alcohol was dried by the method of Lund and Bjerrum (*Ber.*, 1931, **64**, 210), and the aqueous mixtures were made up by volume as described previously (cf. this vol., p. 1179).

Kinetic Measurements.—In the experiments at 25·2° the halide was dissolved in the initially neutral or alkaline medium. At suitable intervals portions were run each into 100 c.c. of absolute alcohol or acetone, and the acid or alkali titrated with standard sodium hydroxide or hydrochloric acid, lacmoid being used as indicator. At similar intervals equivalent portions were run each into 150 c.c. of carbon tetrachloride, and the olefin was estimated as described in the preceding paper. In the experiments at 50·0° portions of the reaction mixtures were enclosed in sealed tubes which were placed in the thermostat for known times, broken under absolute alcohol or carbon tetrachloride as required, and analysed as before.

Hydrolysis of tert.-*Amyl Chloride.*—Typical experiments are recorded in Table III. The first three cols. are self-explanatory. Col. 4 gives the mol.-ratio of olefin to total reaction, and col. 5 the total first-order rate constant ($k_{E1} + k_{S_N1}$) calculated from the formula $k_1 = (1/t).\log_e\{a/(a - x)\}$, where a is the initial concentration of *tert.*-amyl chloride and x the decrease in concentration; a was found by determining the asymptotic value of x (the [HCl]) at large times. In the experiment in alkaline solution (Table III, B), which is not affected by the hydration of the olefin, this constant (k_1') was also determined in a similar manner from the results of the olefin estimations (cf. Part II). Col. 6 records the first-order rate coefficients of the elimination reaction; these are obtained by multiplying the coefficients in col. 5 by the ratios in col. 4. The constants are in sec.$^{-1}$ except where otherwise stated. The hydration of the olefin is illustrated in subsidiary tables.

TABLE III.

Illustrating determination of first-order rate constants of the hydrolysis of tert.*-amyl chloride, and the hydration of the olefinic product.*

A. Solvent: 80% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$Cl] = 0·0787N, and solution neutral. Samples of 20 c.c. titrated. [HCl] expressed as equivalent c.c. of 0·1069N-NaOH and [Olefin] as c.c. of 0·0486N-$Na_2S_2O_3$.

t (hrs.).	[HCl].	[Olefin].	El/(El+S_N1).	10^7k_1.	10^7k_{E1}.	t (hrs.).	[HCl].	[Olefin].	El/(El+S_N1).	10^7k_1.	10^7k_{E1}.
3·00	2·17	3·00	0·314	148	46·5	8·00	5·17	7·73	0·340	150	51·0
4·00	2·84	4·18	0·335	149	49·9	9·00	5·72	8·40	0·334	152	50·7
5·10	3·54	5·08	0·326	150	48·9	10·00	6·16	9·19	0·339	151	51·2
6·00	4·06	5·96	0·334	149	49·8	11·00	6·56	10·00	0·347	149	51·7
7·00	4·63	6·78	0·333	150	50·0						

t (hrs.)	25·0	27·0	29·0	73·5	99·0	124	196	298	445
[HCl]	11·16	11·56	11·76	14·42	14·67	14·71	14·75	14·72	14·72
[Olefin]	13·17	13·58	15·01	16·81	16·79	16·01	15·21	13·56	13·49
El/(El + S_N1)	0·268	0·267	0·290	0·265	0·260	0·247	0·234	0·209	0·208

B. Solvent: 80% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$Cl] = 0·0776N, and [NaOH] = 0·212N. Samples of 20 c.c. titrated. [HCl] (as NaOH neutralised) expressed in c.c. of 0·1564N-HCl and [Olefin] as c.c. of 0·050N-$Na_2S_2O_3$.

t (hrs.).	[HCl].	[Olefin].	El/(El+S_N1).	10^7k_1.	10^7k_{E1}.	$10^7k_1'$.	t (hrs.).	[HCl].	[Olefin].	El/(El+S_N1).	10^7k_1.	10^7k_{E1}.	$10^7k_1'$.
4·00	1·89	4·40	0·372	147	54·6	163	28·1	8·00	16·85	0·337	161	54·3	160
5·00	2·36	5·15	0·349	151	52·7	156	29·3	8·02	16·78	0·334	157	52·4	152
6·00	2·88	5·93	0·329	159	52·2	154	77·3	9·76	20·57	0·337	—	—	—
7·00	3·16	6·27	0·317	152	48·2	141	126	9·92	21·00	0·338	—	—	—
8·00	3·32	7·46	0·359	142	51·0	152	316	9·93	21·40	0·344	—	—	—
9·00	3·83	7·43	0·310	151	46·7	138							

C. Solvent: 80% aqueous alcohol. Temp. 50·0°. Initially [Am$^{\gamma}$Cl] = 0·1471N, and solution neutral. Samples of 10 c.c. titrated. [HCl] expressed in equivalent c.c. of 0·01052N-NaOH and [Olefin] in c.c. of 0·04904N-$Na_2S_2O_3$.

t (min.).	[HCl].	[Olefin].	El/(El+S_N1).	10^6k_1.	10^6k_{E1}.	t (min.).	[HCl].	[Olefin].	El/(El+S_N1).	10^6k_1.	10^6k_{E1}.
15·00	3·00	5·51	0·428	268	115	85·0	10·81	17·93	0·387	291	113
30·0	5·56	9·58	0·402	282	113	120·0	12·38	20·37	0·383	300	115
45·0	7·52	13·20	0·409	286	117	∞	13·98	—	—	—	—
62·0	9·14	15·98	0·408	285	116						

t (hrs.)	7·0	72·0	167	264	600
[Olefin]	21·61	14·80	9·91	7·83	5·68
El/(El + S_N1)	0·359	0·247	0·166	0·131	0·095
10^3k_H (hrs.$^{-1}$)	—	5·81	4·87	3·95	2·27

The olefin concentrations recorded in the lower half of the table were estimated after the completion of the hydrolysis; the acid concentration remained constant. The reversibility of the hydration is indicated by the downward drift in the value of the pseudo-unimolecular coefficient k_H, calculated from the equation $k_H = \frac{1}{t - t_0} \log_e \frac{a_0}{a_t}$, where a_0 and a_t are the olefin concentrations at t_0 and t respectively (t_0 = 7, and a_0 = 21·61).

D. Solvent: 60% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$Cl] = 0·0783N, and solution neutral. Samples of 20 c.c. titrated. [HCl] expressed in equivalent c.c. of 0·1069N-NaOH and [Olefin] in equivalent c.c. of 0·050N-$Na_2S_2O_3$.

t (min.).	[HCl].	[Olefin].	El/(El+S_N1).	10^6k_1.	10^6k_{E1}.	t (min.).	[HCl].	[Olefin].	El/(El+S_N1).	10^6k_1.	10^6k_{E1}.
7·90	0·92	1·05	0·267	137	36·6	85·40	8·00	8·74	0·256	155	39·6
15·27	1·73	1·92	0·260	137	35·6	120·2	9·81	10·90	0·260	154	40·0
21·85	2·49	2·75	0·258	142	36·7	153·9	10·99	12·15	0·258	151	39·0
33·08	3·68	3·93	0·250	147	36·7	210·0	12·69	13·52	0·249	159	39·7
48·97	5·24	5·79	0·258	150	38·8	∞	14·65	—	—	—	—
64·65	6·54	7·35	0·263	152	40·1						

t (hrs.)	24	265	557	865	1300
[Olefin]	14·61	12·10	10·40	9·10	7·82
El/(El+S_N1)	0·233	0·194	0·167	0·146	0·125
10^4k_H (hrs.$^{-1}$)	—	7·83	6·38	5·63	4·90

The acid concentration remained constant in the lower half of the tables; k_H was calculated as in Table III, C (t_0 = 24, a_0 = 14·61).

Hydrolysis of tert.*-Amyl Bromides.*—Two experimen ts are recorded in Table IV, the cols. of which contain the quantities previously defined.

TABLE IV.

Illustrating determination of first-order rate constants of the hydrolysis of tert.*-amyl bromide.*

A. Solvent: 80% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$Br] = 0·0722*N*, and solution neutral. Samples of 20 c.c. titrated. [HBr] expressed in equivalent c.c. of 0·1069*N*-NaOH and [Olefin] in equivalent c.c. of 0·04906*N*-$Na_2S_2O_3$.

t (min.).	[HBr].	[Olefin].	E1/(E1 + S_N1).	10^6k_1.	10^6k_{E1}.	$10^6k_1'$.
3·20	1·40	1·67	0·274	570	156	593
6·50	2·70	3·20	0·272	572	156	593
10·25	4·10	4·59	0·257	589	151	571
14·97	5·50	6·45	0·269	582	157	599
21·30	7·20	8·15	0·260	596	155	584
27·70	8·55	9·49	0·255	604	154	570
36·33	9·90	10·97	0·254	606	154	564
46·13	10·95	12·38	0·259	602	156	579
62·67	11·90	13·31	0·257	567	146	(521)
68·5 hrs.	13·47	15·50	0·264	—	—	—
216 ,,	13·52	14·57	0·248	—	—	—
509 ,,	13·50	14·35	0·244	—	—	—
818 ,,	13·60	13·10	0·222	—	—	—
1154 ,,	13·52	13·25	0·225	—	—	—

B. Solvent: 80% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$Br] = 0·0654*N*, and [NaOH] = 0·1179*N*. [HBr] (as NaOH neutralised) expressed in equivalent c.c. of 0·1564*N*-HCl and [Olefin] in c.c. of 0·04906*N*-$Na_2S_2O_3$.

t (min.).	[HBr].	[Olefin].	E1/(E1 + S_N1).	10^6k_1.	10^6k_{E1}.	$10^6k_1'$.
7·90	2·05	4·05	0·310	593	184	595
28·74	5·25	10·57	0·316	572	181	593
38·74	6·17	12·35	0·314	575	183	594
46·10	6·65	13·24	0·312	572	179	587
60·82	7·30	14·33	0·308	564	174	556
140·4	8·11	15·38	0·297	—	—	—
22 hrs.	8·32	15·28	0·288	—	—	—
174 ,,	8·42	16·50	0·307	—	—	—

Hydrolysis of tert.*-Amyl Iodide.*—Olefin estimations could not be carried out during the hydrolysis owing to a reaction between bromine and the *tert.*-amyl iodide (cf. Part II). The rate constants of the total reaction (k_1) were, however, evaluated in acid and in alkaline solution, and the mol.-ratio of olefin to the total decomposition was obtained from estimations made at the end of the reactions. The hydriodic acid concentration in the experiments in initially neutral solution decreased considerably on prolonged standing, owing presumably to oxidation and formation of iodine. Serious error was, however, avoided by carrying out the estimations as soon as possible after the completion of the reaction. The small amount of iodine which was extracted by the carbon tetrachloride was removed by washing with dilute sodium thiosulphate before estimating the olefin. The results are in Table V.

TABLE V.

Illustrating determination of first-order rate constants of the hydrolysis of tert.*-amyl iodide.*

A. Solvent: 80% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$I] = 0·114*N*, and solution neutral. Samples of 5 c.c. titrated. [Am$^{\gamma}$I] expressed in equivalent c.c. of 0·0526*N*-NaOH.

t (sec.)	116	220	290	358	470	670	932
[Am$^{\gamma}$I]	8·95	7·49	6·62	5·85	4·78	3·20	1·89
10^5k_1	165	168	170	172	174	182	188

In a similar experiment the acid concentration at the end of the reaction was 0·142*N*, and the olefin values in separate determinations, expressed in c.c. of 0·04904*N*-$Na_2S_2O_3$ per 10 c.c. of reaction mixture, were: 14·85, 15·00, 15·20, 15·04, 14·80.

B. Solvent: 80% aqueous alcohol. Temp. 25·2°. Initially [Am$^{\gamma}$I = 0·112*N*, and [NaOH] = 0·112*N*. Samples of 5 c.c. titrated. [Am$^{\gamma}$I] expressed in equivalent c.c. of 0·0782*N*-HCl.

t (sec.)	120	225	310	415	552	718	930
[Am$^{\gamma}$I]	5·85	4·63	4·14	3·50	2·75	1·96	1·31
10^5k_1	168	194	177	173	173	180	183

In a similar experiment the concentration of *tert.*-amyl iodide was 0·131*N*, and the olefin values at the end of the reaction, expressed in c.c. of 0·04904*N*-$Na_2S_2O_3$ per 10 c.c. of the solution, were: 13·07, 13·15, 13·38, 13·20, 12·92, 13·13, 13·17.

We wish to acknowledge with gratitude our indebtedness to Professor C. K. Ingold, F.R.S., for helpful advice and encouragement, and the Ramsay Memorial Fellowships Trust for a grant which enabled one of us (E. D. H.) to participate in the work described in this and the preceding papers.

UNIVERSITY COLLEGE, LONDON. [*Received, April 24th*, 1937.]

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262. *The Spectrum and Molecular Structure of Carbon Suboxide, and Evidence for Hybrid Links.*

By HAROLD W. THOMPSON and J. W. LINNETT.

IN a recent paper, measurements on the ultra-violet absorption spectrum of carbon suboxide were described (Thompson and Healey, *Proc. Roy. Soc.*, 1936, *A*, **157**, 331). As then explained, the analysis of the complex system of diffuse bands observed in the region of

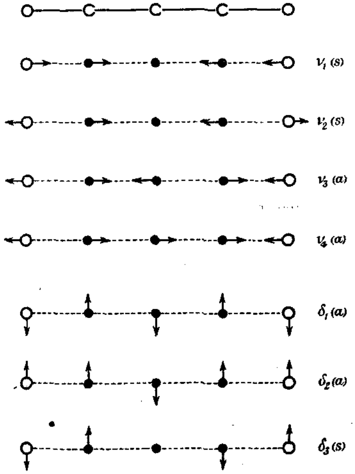
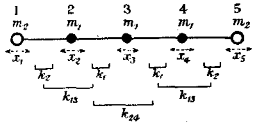


FIG. 1.

FIG. 2.



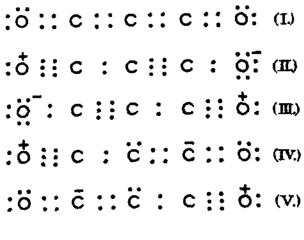


FIG. 3.

3200 A. was made the more difficult since no data were at that time available about the Raman or infra-red vibration frequencies of this molecule. On the basis of the observed intensity distribution, and by a consideration of the rules of Herzberg and Teller (*Z. physikal. Chem.*, 1935, *B*, **21**, 410), an analysis was, however, attempted, and approximate vibration frequencies in the excited electronic state consistent with these rules were determined. The modes of vibration of the molecule are shown in Fig. 1. The values suggested by the spectral work were $\nu_1(s) = 840$, $\nu_2(s) = 2160$, $\nu_4(a) = 1227$, with three smaller deformation oscillations 150, 240, and 540, designated respectively as $\delta_2(a)$, $\delta_3(s)$, and

$\delta_1(a)$. The assignment of the three deformation frequencies to specific modes of vibration was, however, less definite than in the case of the valency vibrations.

It was hoped to make measurements in the photographic infra-red which might provide further evidence. Simultaneously with the publication of the above work, however, Engler and Kohlrausch published measurements, in which the experimental difficulties associated with the determination of the Raman spectrum were overcome (*Z. physikal. Chem.*, 1936, *B*, **34**, 214). The vibration frequencies obtained in the Raman spectrum are remarkably in agreement with those derived from the analysis of the spectrum, in regard to both magnitude and assignment. This provides a striking example of the justification of the use of the rules of Herzberg and Teller in analysing complex spectra, and seems worthy of record. Moreover, there is now sufficiently certain knowledge of the vibration frequencies to make it possible to calculate the linkage force-constants and to draw inferences concerning the molecular structure.

Electron-diffraction measurements have made it almost certain that carbon suboxide has a linear symmetrical structure (Brockway and Pauling, *Proc. Nat. Acad. Sci.*, 1933, **19**, 860; Boersch, *Wien. Ber.*, 1935, **144**, IIb, 1). The symmetry group is then $D_{\infty h}$, and there will be three strong Raman frequencies $\nu_1(s)$, $\nu_2(s)$, and $\delta_3(s)$ (Placzek, *Leipziger Vorträge*, 1931, 71). The Raman measurements confirm this completely. The values found and assigned by Engler and Kohlrausch are $\nu_1(s) = 843$, $\nu_2(s) = 2200$, $\delta_3(s) = 586$. It seems possible that another frequency, 1176, observed very feebly in the Raman effect may be regarded as $2\delta_3(s)$. Alternatively, the two very feeble Raman frequencies found at 1114 and 1176 may arise from impurities which are very difficult to remove from this substance.

It will be seen that the values given by Engler and Kohlrausch for $\nu_1(s)$ and $\nu_2(s)$ agree closely with those determined from the spectrum. It must be remembered that the latter values refer to the excited state, but, as previously explained, Duncan's collected data (*J. Chem. Physics*, 1935, **3**, 384) suggest that no considerable change is, in general, to be expected on electronic excitation. The frequency 586 assigned by Engler and Kohlrausch to $\delta_3(s)$ is paralleled by the magnitude 540 assigned by Thompson and Healey to $\delta_1(a)$. If we adopt the assignment of Engler and Kohlrausch, there is an additional confirmation of the spectral analysis, for the more intense of the weaker bands found will then correspond to the excitation of the symmetric deformation oscillation.

We can therefore now assume that with fair accuracy $\nu_1(s) = 843$ and $\nu_2(s) = 2200$, and it seems, further, unlikely that resonance splitting can lead to perturbed values. The force constants of the linkages of the molecule can now be calculated. The equations connecting the frequencies of the parallel vibrations with the force constants and masses, on the assumption of simple valency force field, *i.e.*, forces only between adjacent atoms connected by a conventional chemical bond, have already been given (Thompson and Healey, *loc. cit.*). By substituting the known frequency magnitudes, imaginary roots are obtained for the force constants. This implies the necessity of introducing " cross-terms " in the potential function expressing the potential energy as a function of the atomic displacements. Engler and Kohlrausch have attempted to make this correction by using a potential function essentially equivalent to that of a central force field. This type of field has, however, in general not proved any more successful than the simple valency force field and frequently less so, and we prefer to use a modified form of the potential function employed by Van Vleck and Cross (*J. Chem. Physics*, 1933, **1**, 357) and by Howard and Wilson (*ibid.*, 1934, **2**, 630), which has been shown to be so satisfactory for many other simple molecules.

For instance, for the water molecule Van Vleck and Cross use the expression

$$V = \tfrac{1}{2}[k_1(\Delta r_1)^2 + k_2(\Delta r_2)^2 + 2k_3 r_1^{\circ 2}(\Delta\gamma)^2 + k_{12}\Delta r_1\Delta r_2 + \sqrt{2}k_{13}r_1^{\circ}(\Delta r_1\Delta\gamma + \Delta r_2\Delta\gamma)]$$

in which r_1, r_2 are the O–H separations, and γ is the angle $\widehat{HOH}$. It transpires that k_{12} is much less than k_1 or k_2 ($k_{12} \simeq 0{\cdot}1k_1$), and that k_{13} is very much smaller than k_{12}. We shall for our present purpose neglect the " cross-terms " involving k_{13}. Howard and Wilson (*loc. cit.*) have similarly found such " angular " cross-terms to be very small in comparison with the " atom-separation " cross-terms.

The parallel vibration frequencies are then derived as follows. Let the masses of carbon and oxygen be respectively m_1 and m_2, and the force constants of the carbon–carbon and carbon–oxygen links be k_1 and k_2, and suppose the displacements of the atoms along the molecular axis are x_1, x_2, x_3, x_4, x_5.

Case I. For the symmetrical frequencies, $x_1 = -x_5$, $x_2 = -x_4$, $x_3 = 0$. Also, regarding contractions of a link as positive, we have

$$\Delta_{12} = x_1 - x_2 \qquad \Delta_{34} = x_3 - x_4$$
$$\Delta_{23} = x_2 - x_3 \qquad \Delta_{45} = x_4 - x_5$$

The kinetic energy is given by

$$T = m_2\dot{x}_1^{\,2} + m_1\dot{x}_2^{\,2} + \tfrac{1}{2}m_1\dot{x}_3^{\,2}$$

The potential function is taken as

$$V = k_1\Delta_{23}^2 + k_2\Delta_{12}^2 + \tfrac{1}{2}k_{13}\Delta_{12}\Delta_{23} + \tfrac{1}{2}k_{35}\Delta_{34}\Delta_{45} + \tfrac{1}{2}k_{24}\Delta_{23}\Delta_{34}$$

in which $k_{13} = k_{35}$. Substituting for $\Delta_{12}, \Delta_{23}, \ldots$, etc., applying Lagrange's equation, and solving the resulting determinantal equation, we have

$$\mu^2 - \mu\left[(k_1 + \tfrac{1}{2}k_{24})\left\{\frac{1}{m_1}\right\} + k_2\left\{\frac{1}{m_1} + \frac{1}{m_2}\right\} - k_{13}\left\{\frac{1}{m_1}\right\}\right] + \left[(k_1 + \tfrac{1}{2}k_{24})k_2\left\{\frac{1}{m_1m_2}\right\} - \frac{k_{13}^2}{4}\left\{\frac{1}{m_1m_2}\right\}\right] = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

in which the frequencies ν are given by $\nu = \sqrt{\mu}/2\pi$. If the masses are expressed in atomic weights, and we write $\mu = \nu^2 \times 5{\cdot}863 \times 10^{-2}$, *the force constants are given in dynes per cm.*

Case II. Similarly for the antisymmetric frequencies, $x_1 = x_5$, $x_2 = x_4$, introduction of a condition for no translation gives

$$m_1\,(x_2 + x_3 + x_4) + m_2\,(x_1 + x_5) = 0$$

The expressions for the kinetic and potential energies being used as before, the solution is

$$\mu^2 - \mu\left[(k_1 - \tfrac{1}{2}\,k_{24})\left\{\frac{3}{m_1}\right\} + k_2\left\{\frac{1}{m_1} + \frac{1}{m_2}\right\} - k_{13}\left\{\frac{1}{m_1}\right\}\right] + \left[k_2(k_1 - \tfrac{1}{2}\,k_{24})\left\{\frac{3}{m_1m_2} + \frac{2}{m_1^2}\right\} - \frac{k_{13}^2}{4}\left\{\frac{3}{m_1m_2} + \frac{2}{m_1^2}\right\}\right] = 0 \quad . \quad . \quad . \quad (2)$$

Considering first the symmetrical vibrations given by equation (1), we have two known frequencies but four unknown constants. If the pair of antisymmetric frequencies were known, we should be able to solve equations (1) and (2) for the four constants. In the circumstances, however, the only alternative is to attempt to determine the values of the constants k_{13} and k_{24} from other data. A molecule which is apparently highly suitable for this purpose is carbon dioxide. For this molecule $m_1m_2m_3$ in which $m_1 = m_3$, using the potential function $V = 2\{\tfrac{1}{2}k_1\Delta_{12}^2\} + \tfrac{1}{2}k_{13}\Delta_{12}\Delta_{23}$, we obtain expressions for the parallel vibrations:

$$\text{Symmetric: } \mu = (k_1 + \tfrac{1}{2}k_{13})\left\{\frac{1}{m_1}\right\}$$

$$\text{Antisymmetric: } \mu = (k_1 - \tfrac{1}{2}k_{13})\left\{\frac{1}{m_1} + \frac{2}{m_2}\right\}$$

The difficulty here arises from uncertain values of the two vibration frequencies. This is the result of resonance splitting caused by the fact that $\nu_1(s) \simeq 2\delta(s)$. Adel and Dennison (*Physical Rev.*, 1933, **46**, 716) attempted to determine the unperturbed values of the frequencies, and gave $\nu_1(s) = 1320$, and $\nu_2(a) = 2350$. Insertion of these values into the above expressions gives $k_1 = 15{\cdot}24 \times 10^5$ and $k_{13} = 2{\cdot}22 \times 10^5$. Assuming the same values for the carbon dioxide frequencies and taking k_{13} as zero, Penney and Sutherland

(*Proc. Roy. Soc.*, 1936, *A*, **156**, 654) found $k_1 = 16{\cdot}4 \times 10^5$ and $14{\cdot}1 \times 10^5$, mean $15{\cdot}2 \times 10^5$, in agreement with our present value.

For carbon suboxide, the values of both k_{13} and k_{24} will be close to that of k_{13} in carbon dioxide. We may expect some minor alteration, however, and examination of other related cases such as that of carbon disulphide suggests that we may reasonably take for carbon suboxide the values $k_{13} = 2{\cdot}3 \times 10^5$, and $k_{24} = 2{\cdot}4 \times 10^5$. Using these values, we can now employ the two symmetrical frequencies and equation (1) and find $k_2 = 14{\cdot}87 \times 10^5$ or $8{\cdot}76 \times 10^5$, with corresponding values of k_1 of $14{\cdot}15 \times 10^5$ or $24{\cdot}86 \times 10^5$. The second pair of values is clearly impossible, and the first must therefore be taken.

It is now of interest to compare these values with the "normal" values of the force constants for the various carbon–carbon and carbon–oxygen linkages. These "normal" values must be determined from molecules in which the linkages are definitely undisturbed by such phenomena as resonance (mesomerism). For the carbon–carbon linkages such molecules would appear to be ethane, ethylene, and acetylene. In ethane, using the potential function of Dennison and Sutherland (*Proc. Roy. Soc.*, 1935, *A*, **148**, 250), we find that $k_{CC} = 4{\cdot}96 \times 10^5$. If a potential function of the Van Vleck and Cross type is used, the value is *ca.* $4{\cdot}9 \times 10^5$. For ethylene, Dennison and Sutherland give $k_{CC} = 9{\cdot}79 \times 10^5$. In a succeeding paper it will be shown that, if other potential functions are used, the value of k_{CC} is approximately $9{\cdot}0 \times 10^5$. It is clear that the true value is close to this. The force constant of the carbon–carbon link in acetylene is given in a later paper as $15{\cdot}73 \times 10^5$, and in deuteroacetylene it is $15{\cdot}93 \times 10^5$. The abnormally high value of the carbon–hydrogen constant in these molecules suggests that there may be some unexpected peculiarity about their structure, leading to a value for the carbon–carbon constant which is not quite "normal"; but there is no doubt that the carbon–carbon triple bond has a force constant close to $15{\cdot}8 \times 10^5$.

For the carbon–oxygen single bond we can regard methyl alcohol as a diatomic system (H_3C)–(OH), which gives a value $4{\cdot}99 \times 10^5$ (Sidgwick, "The Covalent Link," p. 123), or we can take the value given by Dennison and Sutherland, *viz.*, $4{\cdot}96 \times 10^5$. The most satisfactory unperturbed carbon–oxygen double link would appear to be that in formaldehyde. The accurate assignment of the several frequencies is difficult in this case, owing to the possibility of resonance splitting. Dennison and Sutherland (*loc. cit.*) give $k_{CO} = 13{\cdot}45 \times 10^5$. In a succeeding paper a somewhat lower value is obtained, but it is clear that the value is close to 13×10^5. In carbon monoxide we have what must approach to a triple bond between carbon and oxygen, and the frequency 2169 gives $k_{CO} = 18{\cdot}6 \times 10^5$ (Sidgwick, *op. cit.*, p. 123). We thus have:

Force constant ($\times 10^5$) of:	Carbon–carbon link.	Carbon–oxygen link.
Normal single	4·9	4·98
Normal double	9·5	13·0
Normal triple	15·8	18·6
In carbon suboxide	14·9	14·15

From these figures it is at once clear that in carbon suboxide the carbon–carbon and the carbon–oxygen linkages are not simple double bonds. This is particularly noticeable of the former, which behave almost, but not entirely, like triple bonds. This is moreover true, even if we assume the potential function used by Kohlrausch, which gives $k_{CO}^{*} = 13{\cdot}9 \times 10^5$ and $k_{CC} = 11{\cdot}1 \times 10^5$. (Actually, if we take Kohlrausch's values it might be more accurate to compare them with the values calculated for the "normal" constants by using a similar type of potential function.) The structure of the molecule might then be represented by a formula of the type O⩸C⩸C⩸C⩸O. The possibility of such a structure arising from resonance (mesomerism) between structures (I), (II), and (III) of the five possible forms shown in Fig. 3 has been suggested by Pauling and Brockway on the basis of electron-diffraction measurements and this result appears to provide a good example of the way in which mesomerism can be detected in simple molecules by a study of link force constants. According to Brockway and Pauling, the C–C distances are $1{\cdot}29 \pm 0{\cdot}03$ A., and the C–O $1{\cdot}20 \pm 0{\cdot}02$ A.; and according to Boersch, they are 1·27 A. and 1·18 A. Double bonds being assumed throughout, addition of the covalent radii gives 1·34 A.

and 1·27 A. Now, according to Badger's empirical rule (*J. Chem. Physics*, 1934, **2**, 128)

$$(r_e - d_{ij}) = \sqrt[3]{1{\cdot}86 \times 10^5/k_{ij}}$$

where d_{ij} in the present case is 0·68 for each link. Taking the values found above for the force constants, we find $r_{CC} = 1{\cdot}20$ A., and $r_{CO} = 1{\cdot}18$ A. Agreement with the electron-diffraction data is therefore not exact as is indeed not surprising, but it is certain that the linkage lengths are far below those required for normal double bonds.

All the above considerations suggest that it may be profitable to consider in a similar manner the force constants of links in related series of molecules, and use the results as a guide to the nature of the bonds involved. This subject is carried further in papers shortly to follow.

Finally, by assuming the force constants determined above for the linkages in carbon suboxide, it is also possible at once to calculate the magnitude of the two antisymmetrical vibration frequencies which have so far not been determined experimentally. The required formula was given above (2). The calculated values are $\nu_3(a) = 2505$, $\nu_4(a) = 1618$. According to Kohlrausch, they would be $\nu_3(a) = 2458$, $\nu_4(a) = 1627$.

SUMMARY.

Recent values of the vibration frequencies of the carbon suboxide molecule, determined by Engler and Kohlrausch's Raman spectral measurements, confirm values previously derived from a study of the ultra-violet absorption spectrum, and strikingly justify the use of the rules of Herzberg and Teller in analysing complex spectra.

By a consideration of the vibration frequencies of the molecule and by a choice of a suitable potential-energy function for the vibrations, the force constants of the linkages in the molecule have been calculated. The values obtained clearly show the existence of a resonance hybrid structure agreeing with previous independent results of Brockway and Pauling.

The antisymmetric vibration frequencies of the molecule have been calculated.

We are grateful to The Government Grant Committee of The Royal Society for a grant in connexion with the experimental side of the above work, and to The Department of Scientific and Industrial Research for a maintenance grant to one of us.

THE OLD CHEMISTRY DEPARTMENT,
UNIVERSITY MUSEUM, OXFORD. [*Received, May 4th*, 1937.]

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263. *The Passivity of Metals. Part VIII. The Rate of Growth of Oxide Films on Iron.*

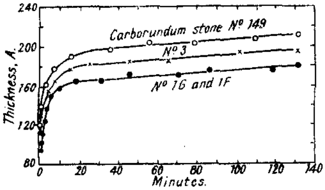
By H. A. MILEY and U. R. EVANS.

An electrical method of estimating oxide films, previously checked by comparison with optical and gravimetric determinations, has been used to obtain time-thickness curves, which show that even at the ordinary temperature the oxidation of iron in dry air is very rapid. The parabolic law is not in general obeyed. Combining the new observations with those of other authors, it appears that the film responsible for the colours on heat-tinted iron is α-Fe_2O_3 above 200°; above 400° this is backed by magnetite, and above 575° a third layer, essentially ferrous oxide, appears. Probably the film formed below 200° is γ-Fe_2O_3.

THE invisible oxide formed on unheated iron during exposure to air can play an important part in predisposing the metal to passivity. W. J. Muller and Machu (*Sitzungsber. Akad. Wiss. Wien*, 1932, **141**, 279; *Z. physikal. Chem.*, 1932, *A*, **161**, 411) found that the "time of passivation" of iron after air-exposure was only 1/20,000 that of iron in the film-free state. One of the authors has shown that pre-exposure to air reduces the probability of attack or depresses the number of starting points of corrosion in certain liquids (Evans, J.,

1927, 1030; Mears and Evans, *Trans. Faraday Soc.*, 1935, **31**, 532; Britton and Evans, *Trans. Electrochem. Soc.*, 1932, **61**, 446); pre-exposure to air has, however, little effect where the liquid is strongly corrosive or where it can itself produce passivity. Early film-stripping experiments suggested that the growth of the film was rapid (Evans, J., 1927, 1029); probably the ragged films obtained by stripping iron immediately after abrasion originate in the intense but transitory heating which accompanies all abrasion, as indicated by Bowden and Ridler (*Proc. Roy. Soc.*, 1936, *A*, **154**, 640); but the fact that iron exposed to air before stripping yields more continuous flakes points to a relatively rapid filling in of the larger discontinuities in the ragged film, although air-formed films never become "protective" in any general sense. The same rapidity of oxidation was indicated optically by Freundlich, Patscheke, and Zocher (*Z. physikal. Chem.*, 1927, *A*, **128**, 321; 1927, **130**, 289) and by Tronstad and Höverstad (*ibid.*, 1934, **170**, 172). The electron-diffraction work of Dobinski (*Nature*, 1936, **138**, 31; *Phil. Mag.*, 1937, **23**, 397) indicates that metal polished in air is heavily oxidised (on metal polished below benzene or pentane no oxide was detected, although it appeared on subsequent exposure to air). Similar results have been obtained by Nelson (*Nature*, 1937, **139**, 30; *J. Chem. Physics*, 1937, **5**, 252) and by Preston and Bircumshaw (*Phil. Mag.*, 1935, **20**, 706); Iitaka, Miyake, and Iimori (*Nature*, 1937, **139**, 156) have applied electron-diffraction study to the films produced on iron by air or by chromate, after stripping by the method of Evans (J., 1927, 1022), and have confirmed several of his conclusions.

FIG. 1.



Oxidation of iron in a desiccator at 18° after different abrasions.

Vernon thinks that his weight–time curves (*Trans. Faraday Soc.*, 1935, **31**, 1676) indicate a much slower oxidation rate, but Price (unpublished work) considers that Vernon's results are consistent with the views expressed above.

Evidently a full understanding of passivity demands a knowledge of the rate of formation of oxide on iron during air exposure. Since gravimetric measurements of oxidation require knowledge of the amount of oxide present at the time of the first weighing, an electrometric procedure has been developed, depending on the number of millicoulombs needed to reduce the film from the ferric to the ferrous state. A similar principle had been applied to measure silver iodide films, where it agreed with gravimetric and iodometric measurements (Evans and Bannister, *Proc. Roy. Soc.*, 1929, *A*, **125**, 380), whilst for oxide films it has been found to agree both with optical results, and with gravimetric results when corrected for the original oxide (Evans and Miley, *Nature*, 1937, **139**, 283). The experimental method described by one of the authors (Miley, *Carnegie Schol. Mem.*, 1936, **25**, 197) was adopted, ammonium chloride being used as the electrolyte, together with a constant current, so that a measurement of time alone sufficed to indicate the millicoulombs needed for the cathodic reduction of the ferric oxide (insoluble in ammonium chloride) to ferrous oxide (which dissolves readily).

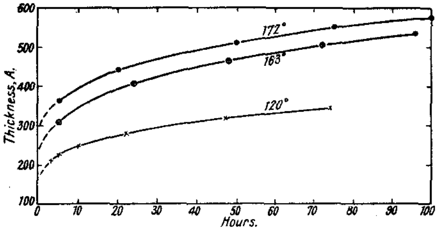
Throughout this paper, the word "thickness" denotes the ***mean general intercept***, *i.e.*, the average of the intercepts made by the film on a large number of parallel lines drawn at right angles to the *general* plane of the surface.

Materials.—Iron, prepared from the carbonyl and of German origin, rolled to thickness of 0·38 mm., was employed. This is almost free from metallic impurities, and usually contains < 0·03% of carbon. The sheet was coarse-grained and probably not quite free from porosity. The standard finish consisted of grinding with French emery No. 1G, finishing with No. 1F, and washing with benzene. In some experiments for comparative purposes the specimens were ground with French emery No. 3 or with a carborundum stone No. 149. In the low-temperature experiments, the specimens were kept in a desiccator filled with calcium chloride and soda-lime in a room kept at 18° by a thermostat. Some experiments at higher temperatures were carried out in a thick-walled electric furnace of high heat capacity. The

specimens were kept at the required temperature for different times, and the oxide present estimated electrically.

Results.—The time-oxidation curves are shown in Figs. 1, 2, and 3. They confirm the view that, even at ordinary temperatures, oxidation is a rapid process. The rate of oxidation decreases as the oxide produced accumulates, but there appears to be no limiting thickness;

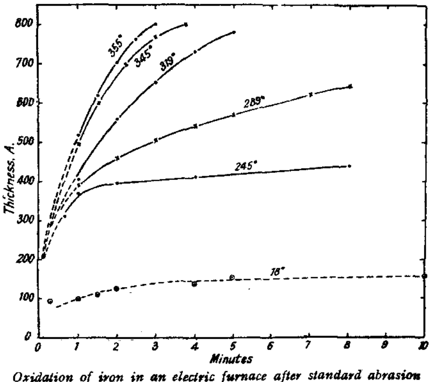
FIG. 2.



Oxidation of iron in an electric furnace after standard abrasion.

the experiment at 163° was continued for 25 days, and the thickness was still increasing. The usual parabolic law connecting mean film-thickness (y) and time (t), *viz.*, $dy/dt = k/y$ or $y^2 = k't + k''$, was not in general obeyed. This is not surprising, since the physical basis of the law (often valid for thick films and high temperatures) requires a film thick compared with the corrugations and disorganised layer of the surface—a condition which is absent on the specimens studied.

FIG. 3.



Oxidation of iron in an electric furnace after standard abrasion (broken curve obtained from the data of Fig. 1).

Composition of the Film.—Early film-stripping work (Evans, J., 1927, 1027) suggested that the films produced at lower temperatures consisted only of ferric oxide, but that at somewhat higher temperatures, a magnetite layer appeared below the ferric oxide; the interference colours were determined by the thickness of the ferric oxide layer. Pfeil (*J. Iron Steel Inst.*, 1929, **119**, 501; 1931, **123**, 237) found that, immediately below 575°, there were two layers

(ferric oxide and magnetite), whilst above 575° a third layer appeared (essentially ferrous oxide but containing more oxygen than corresponds to the formula FeO).

During the electrical estimations of film-thickness mentioned above, it was noticed that metal oxidised below 375° became clean and bright after the cathodic reduction; but if the metal had been tinted above 400° there remained, after the removal of the colour film, a black deposit on the metal surface, evidently the magnetite present at the base of the ferric oxide. To ascertain whether the outer "colour-film" was really ferric oxide, certain specimens were tinted, washed in water, alcohol, and ether, dried in a vacuum, weighed, and then subjected to cathodic reduction for a time *insufficient* to reduce the oxide completely; after being again washed and dried they were reweighed. A comparison between the weight-loss measured directly and that calculated from the millicoulombs on the assumption that the film is ferric oxide and becomes reduced to the ferrous state shows good agreement (see table); numbers calculated on the assumption that the film was magnetite would have been 1·47 times greater. Evidently the colour-film is ferric oxide, not magnetite.

Comparison Between Millicoulombs Expended and Weight-loss (in mg./dm.^{2}).

Weight-loss (calc. from millicoulombs)	0·63	0·59	0·62	0·56	0·95	0·98	0·92	0·90
Weight-loss (gravimetric)	0·61	0·57	0·63	0·54	0·96	0·95	0·89	0·86

This quantitative relation was not found for films produced below 200°. Vernon (*Trans. Faraday Soc.*, 1935, **31**, 1674) had previously noticed differences in the films formed below and above 200°; amounts of oxide, which, if produced above 200°, would have sufficed to give colours, produced no colours when formed below this temperature. This fact was also confirmed when electrical estimation was employed. Preston and Bircumshaw (quoted by Vernon) found, by electron diffraction, that oxide formed below 200° was either γ-ferric oxide or magnetite, whereas above 200° it was α-ferric oxide. Iitaka, Miyake, and Iimori (*loc. cit.*), after determining by electron diffraction the structure of the films formed at ordinary temperatures and stripped from the metallic basis, concluded that they were either γ-ferric oxide or magnetite. They then performed chemical tests which decided in favour of the former.

If the Japanese authors' conclusions are accepted, the abnormally low weight-loss suffered by specimens tinted below 200° on partial reduction in ammonium chloride can be tentatively explained by assuming that ferrous oxide from γ-ferric oxide is not as quickly soluble in ammonium chloride as is that from α-ferric oxide. This is supported by the observation that these specimens gain in weight on subsequent exposure to air, reaching a constant value—presumably when the residual ferrous oxide has become completely reoxidised. Specimens tinted above 200° do not show this weight increase.

It seems, therefore, fairly certain that the thin films formed on iron in air are: Below 200°, one layer, γ-Fe_2O_3; between 200° and 400°, one layer, α-Fe_2O_3; between 400° and 575°, two layers, α-Fe_2O_3 and Fe_3O_4; above 575°, three layers, α-Fe_2O_3, Fe_3O_4, and "FeO."

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264. *Studies in Tar Hydrocarbons. Part I. Reduction Products of Pyrene.*

EDWARD A. COULSON.

SINCE the discovery that pyrene is comparatively plentiful in, and can be readily isolated in quantity from, certain hydrogenated tar fractions (B.P. 435,254 of 1935) it has attracted renewed interest. In particular, the arrangement of the double bonds and the location of residual affinity or points of attack in this aromatic type are of theoretical interest (Goldschmiedt, *Annalen*, 1907, **351**, 231; Clar, *Ber.*, 1936, **69**, 1671).

Catalytic Reduction of Pyrene.—Very few pyrene derivatives of ascertained constitution are known. With the object of preparing such derivatives as reference compounds from hydrogenated pyrenes, in which the possibilities of isomerism are less complicated, and which can be transformed by dehydrogenation into the corresponding pyrene derivatives,

the preparation of the two known hexahydropyrenes was studied. One of these (Graebe, *Annalen*, 1871, **158**, 297) was proved to be the symmetrical or 3 : 4 : 5 : 8 : 9 : 10-isomeride (II) by Cook and Hewett (J., 1933, 401), who tried to reduce pyrene catalytically in tetralin solution with a nickel catalyst in order to obtain a good yield of this hexahydride, but favoured the sodium–boiling amyl alcohol method of Goldschmiedt, although it gave only 23% of a theoretical yield of the *s*.-hexahydride and less than 2% of a second hexahydropyrene—the *as*.-derivative (VI)—the only other pure product isolated.

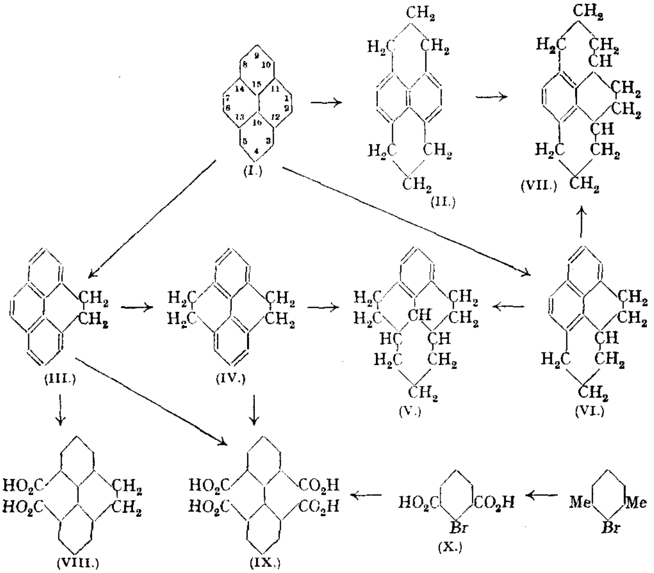
In B.P. 435,254 it is stated that the presence of pyrene in hydrogenated tar oils is due to a characteristic resistance to hydrogenation but also that pyrene is hydrogenated at 300° with a nickel catalyst under an initial pressure of 80 atmospheres of hydrogen to the *s*.-hexahydride and that this may be converted into decahydropyrene at 210° with an initial pressure of 90 atmospheres. As these experimental conditions are by no means extreme, it became of interest to examine the effect of a molybdenum–sulphur–active charcoal catalyst on the reduction of pure pyrene. Contrary to expectation it was found that, even when the hydrocarbon was sealed with 100 atmospheres of hydrogen and 10% by weight of catalyst and heated to 400°, reduction occurred very slowly and at least two-fifths of the pyrene remained unchanged after 4 hours. *s*.-Hexahydropyrene (2% of theoretical) and a new 1 : 2-*dihydropyrene* (III), m. p. 132° (8% of theoretical), were the only other identifiable solid products. When the time of reaction was increased to 6 hours, other conditions remaining unchanged, there was still 43% of unreduced pyrene but, beside 7·5% of *s*.-hexahydride, the product contained 28% of a mixture of the 1 : 2-di- and the *as*.-hexa-hydropyrene difficult to separate, *ca*. 10% of a new 1 : 2 : 6 : 7-*tetrahydropyrene* (IV), m. p. 138°, 2% of naphthalene due to some cracking, and a residue of oily products obviously decahydropyrenes. These results were sufficient to show that good yields of either *s*.- or *as*.-hexahydropyrene are not obtainable by reduction with a molybdenum–sulphur–carbon catalyst at high temperatures.

Pestemer and Manchen (*Monatsh.*, 1936, **68**, 92) have, on the basis of ultra-violet absorption spectra, characterised a " dihydropyrene, m. p. 106° " and a " tetrahydropyrene, m. p. 84° " isolated by Zinke and Ristic (*Diss.*, Graz, 1936) from the products of sodium–amyl alcohol reduction of pyrene as mixtures of pyrene and *s*.-hexahydropyrene. They overlooked the likelihood that *as*.-hexahydropyrene was present in these mixtures.

Reductions with Sodium in Amyl Alcohol.—When pyrene was reduced as described by Cook and Hewett (*loc. cit.*), there was isolated from the product by an improved method 27% of the calculated amount of *s*.-hexahydride and a somewhat smaller yield of the *as*.-isomeride. Crystallisation of the more soluble, non-picrate-forming residue furnished a substance, m. p. 63°, which contained more hydrogen than a pure hexahydro-derivative and was apparently composed of equal mols. of tetra- and deca-hydropyrenes in some kind of association. The residue of liquid products, which do not form picrates in alcohol, consists evidently of decahydropyrenes. It is possible that careful regulation of the amount of sodium would permit the isolation of pure di- and tetrahydro-pyrenes, but under the conditions employed these as well as the *as*.-hexahydride, but unlike the *s*.-hexahydride, are very easily reduced. Thus 1 : 2-dihydropyrene gives the 1 : 2 : 6 : 7-tetrahydropyrene, which itself is easily reduced to 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-*decahydropyrene* (V), m. p. 68°, isomeric with the 1 : 2 : 3 : 4 : 5 : 8 : 9 : 10 : 11 : 12-decahydropyrene (VII) prepared synthetically by v. Braun and Rath (*Ber.*, 1928, **61**, 956). The latter isomeride is in fact formed very slowly when *s*.-hexahydropyrene is treated with a great excess of sodium in boiling amyl alcohol. Reduction of *as*.-hexahydropyrene gives a product which apparently contains both decahydropyrenes and is only partly solid at room temperature. The diagram on p. 1300 summarises the course of the reduction reactions.

In the examination and separation of the di-, tetra-, hexa-, and deca-hydropyrenes great assistance is furnished by the variations in the stability of the corresponding picrates. Pyrene picrate is stable and sparingly soluble in alcohol and melts at 228°; mixtures containing pyrene and any hydrogenation product can be readily freed from pyrene by crystallisation from alcohol containing excess of picric acid. The picrates of *s*.-hexahydropyrene (II) and 1 : 2 : 6 : 7-tetrahydropyrene (IV) are not stable in presence of alcohol or ether, but can be formed in dry benzene. 1 : 2-Dihydropyrene (III) and *as*.-hexahydro-

pyrene (VI) form picrates, m. p. 147° and 148°, which are quite stable in alcohol and have roughly the same solubility. When mixed, they slightly depress one another in m. p. The two decahydrides do not form picrates and are very soluble in both alcohol and petrol.

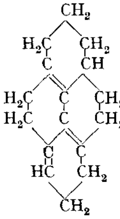


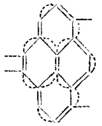
Constitutions of 1 : 2-*Dihydro*-, 1 : 2 : 6 : 7-*Tetrahydro*-, 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16- *and* 1 : 2 : 3 : 4 : 5 : 8 : 9 : 10 : 11 : 12-*Decahydro-pyrenes*.—The evidence for the assigned constitutions of the di- and the tetra-hydride (III and IV) is based on oxidation. Both, when oxidised with potassium permanganate, furnished diphenyl-2 : 6 : 2′ : 6′-tetracarb-*oxylic acid*. An authentic specimen of this acid was prepared by an improved method from *m*-2-xylidine through 2-*bromo*iso*phthalic acid* (X). No alternative formulation of the tetrahydro-derivative is, therefore, possible and the dihydro-derivative must be either 1 : 2- or 1 : 6-dihydropyrene. When oxidised with hydrogen peroxide in acetic acid, it gave a substance whose composition and properties agreed with 9 : 10-*dihydrophenanthrene*-4 : 5-*dicarboxylic acid* (VIII). This rules out the 1 : 6-orientation, since the two hydrogen atoms must be homonuclear.

Of the ten hydrogen atoms in the decahydride prepared from the tetrahydride, the positions of four have been determined. The tetrahydride is a diphenyl derivative, as its oxidation clearly shows, and would be expected to be reduced fully in one aromatic ring. When treated with boiling potassium permanganate solution, the decahydride is not readily destroyed and no hemimellitic acid could be isolated from the small amount of acidic oxidation product, but this decahydride is not identical with the decahydride prepared from the s.-hexahydropyrene and the assigned formula, 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-decahydropyrene (V), is preferred to others, such as (XI), which would require the existence of non-aromatic double bonds.

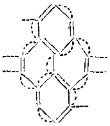
Similar grounds justify the formula assigned to the decahydride derived by reduction of s.-hexahydropyrene, of which the constitution as 3 : 4 : 5 : 8 : 9 : 10-hexahydride (II) and therefore as a naphthalenoid hydrocarbon was determined by Cook and Hewett (*loc. cit.*). The melting point of this 1 : 2 : 3 : 4 : 5 : 8 : 9 : 10 : 11 : 12-decahydropyrene (VII) was higher than is given by v. Braun and Rath for the synthetical specimen. It may be observed that possibilities of *cis-trans* isomerism of the decalin type exist in both decahydrides, although so far unrealised. It is possible that v. Braun and Rath's synthetical specimen contained a different ratio of the two isomerides which accounts for its lower m. p. A liquid decahydride is referred to by Matsuno and Han (*Bull. Chem. Soc. Japan*, 1936, **11**, 321), who do not state its origin but assign to it the formula given by v. Braun and Rath to the crystalline synthetical specimen. If this liquid were obtained, as seems likely, by the catalytic hydrogenation of pyrene, it may contain five isomerides, because the 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-decahydride derived from the 1 : 2 : 6 : 7-tetrahydride will be present in addition (3 forms).

The Structure of Pyrene.—The arrangement of the double bonds in the four nuclei excited the attention of Goldschmiedt (*loc. cit.*), who put forward the Thiele formula (XII), which contains a *p*-quinonoid nucleus, on the basis of the persistent yellow colour of the hydrocarbon.

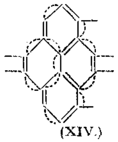
(XI.) 



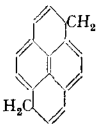
(XII.)



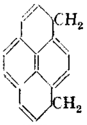
(XIII.)



(XIV.)



(XV.)



(XVI.)

Winterstein, Schön, and Vetter (*Z. physikal. Chem.*, 1934, **230**, 146) showed that the colour of the hydrocarbon prepared from tar oils was due to a so-called "chrysogen," pure pyrene being colourless. It is curious that, although the formulation predicted reactivity in the 1 : 2-positions, no evidence of such reactivity was adduced or even sought. When pyrene reacts with aryl chlorides, condensation occurs in the 3 : 8- and 3 : 10-positions (Scholl and Seer, *Annalen*, 1912, **394**, 121). There is no evidence to differentiate between a 3 : 8- and 3 : 10-orientation for the quinone formed by oxidation. In the latest study of the structure of pyrene based on absorption spectra, Clar (*Ber.*, 1936, **69**, 1671) finds evidence that the 3 : 8-positions are reactive, but the 1 : 2-positions are subsidiary centres. Goldschmiedt's formula must therefore be rejected.

There are only two other acceptable arrangements of the double bonds (as in XIII and XIV) and application of Thiele's principles leads to the conclusion that (XIV) would be the equivalent of Goldschmiedt's formula (XII) predicting 3 : 10-activity and therefore inadmissible, although its acceptance would be more fully in accordance with the principle set up by Fries, Walter, and Schilling (*Annalen*, 1935, **516**, 248) that in a polynuclear hydrocarbon the double bonds are arranged to give the maximum number of benzenoid rings.

There is no difficulty in explaining the experimental facts of hydrogenation on either formula. If the 3 : 8- or 3 : 10-carbon atoms are attacked initially, the first formed dihydrides (XV and XVI) will in either case be rapidly reduced to the stabler *s*.-hexahydropyrene (II) in which the two unattacked nuclei have become naphthalenoid. Again, if the initial attack occurs in the 3 : 2-, 3 : 1-, 3 : 6- or 3 : 7-positions in either (XIII) or (XIV), it will continue until finally the *as*.-hexahydropyrene (VI, again a naphthalenoid system) is formed. The stable 1 : 2-dihydropyrene (III) results if initial attack occurs in the 1 : 2- or 6 : 7-positions. This is regarded as phenanthrenoid, because when subjected to further reduction it is attacked (at the 6 : 7-positions) in what corresponds to the 9 : 10-positions of phenanthrene (cf. Burger and Mosettig, *J. Amer. Chem. Soc.*, 1935, **57**, 2731) and the resultant tetrahydropyrene (IV) has the stable benzenoid arrangement of bonds present in diphenyl. If initial attack occurs at the 1 : 6- or 1 : 7-positions, a stable arrangement is not reached until four hydrogen atoms have been added to give the benzenoid tetrahydropyrene (IV).

It will be seen that the course of hydrogenation gives experimental proof, hitherto lacking, that reactive centres are present in the 1 : 2- and possibly the 6 : 7-positions in the pyrene nucleus as well as in the 3 : 8- or 3 : 10-positions. If the structure of pyrenequinone is definitely decided as a 3 : 8-derivative, (XIII) must be accepted as the best representation of the structure and reactivity of pyrene.

EXPERIMENTAL.

Catalytic Hydrogenation of Pyrene with a Molybdenum-Sulphur–Carbon Catalyst.—(a) *Short reaction period* : 1 : 2-*Dihydropyrene* (III). Pyrene (50 g.) was placed in a 500 c.c. autoclave with hydrogen at 100 atms. and a catalyst made by impregnating 5 g. of active charcoal with a solution of 1 g. of molybdenum trioxide in aqueous ammonia, drying the mixture at 100°, and adding 1 g. of flowers of sulphur. The temperature was raised to 400° and maintained for 4 hours. After cooling, the pressure was 80 atms. The product, a solid, was dissolved away from the catalyst with ether and treated in boiling alcohol (500 c.c.) with 50 g. of picric acid. After removal of 40 g. of pyrene picrate, m. p. 220°, by crystallisation (it is only slightly soluble in cold alcohol) the mother-liquor was concentrated; a mixture of colourless needles of *s*.-hexahydropyrene and red needles of the mixed picrates of 1 : 2-dihydro- and *as*.-hexahydro-pyrene slowly crystallised. These were separated by repeated washing with cold alcohol, which dissolved the picrates more rapidly than the hydrocarbon. *s*.-Hexahydropyrene (1 g.) was obtained pure, m. p. 132°, not depressed by a specimen made by Goldschmiedt's method. The picrates were purified from traces of pyrene picrate by repeated extraction with cold alcohol and by crystallisation and a yield of 8 g., m. p. 142—149°, obtained, but this still contained some of the picrate of *as*.-hexahydride, as the hydrocarbon recovered after treatment with aqueous ammonia melted at 122°. On recrystallisation from alcohol, pure 1 : 2-*dihydropyrene* (II) (1·5 g.) was obtained in colourless satin-lustred flakes, m. p. 132° (Found : C, 93·7, 93·8; H, 6·0, 6·1. $C_{16}H_{12}$ requires C, 94·1; H, 5·9%). The *picrate* crystallised in bright red needles, m. p. 147° (Found : C, 60·7; H, 3·7. $C_{16}H_{12},C_6H_3O_7N_3$ requires C, 60·9; H, 3·5%), fairly soluble in alcohol but only very slightly soluble in petrol (b. p. 40—60°); it appeared to be rather more stable than the picrate of *as*.-hexahydropyrene, which it otherwise closely resembled. A mixture with the latter, m. p. 148°, melted at 143°.

When heated at 300° for 6 hours with selenium, the hydrocarbon was dehydrogenated to pyrene, isolated in good yield and identified by comparison with an authentic specimen.

(b) *Longer reaction period* : 1 : 2 : 6 : 7-*Tetrahydropyrene* (IV). Pyrene (100 g.) was hydrogenated in a 2 l. autoclave for 6 hours, all other conditions being as in (a). After removal of pyrene (43 g.) as picrate the product yielded 61·0 g. of mixed picrates of di- and *as*.-hexa-hydropyrene, m. p. *ca*. 140°, and 7·5 g. of pure *s*.-hexahydropyrene. The residual material (18 g., only partly solid) was warmed with 10 g. of picric acid till all had dissolved and the cooled mixture was triturated with petrol (b. p. 40—60°) to remove the hydrocarbons which did not form stable picrates. Picric acid and fairly pure 1 : 2-dihydropyrene picrate remained, but some 1 : 2-dihydropyrene passed into the petrol solution and it was only completely removed from the non-picrate-forming hydrocarbons by a second warming with picric acid and trituration with cold petrol. After removal of dihydropyrene the liquid portion of the hydrocarbons was separated, and the remaining solid (8 g.) fractionally crystallised from alcohol to yield roughly equal amounts of *s*.-hexahydropyrene and the more soluble 1 : 2 : 6 : 7-*tetrahydropyrene* (IV).

The liquid portion of the residual hydrocarbons was fractionally distilled in a vacuum; the most volatile portion crystallised and was recognised as naphthalene (2 g.); the higher-boiling fractions also crystallised slowly in part and from the solid a little more of both the *s*.-hexahydro- and the tetrahydro-pyrene was separated.

Considerable difficulty was experienced in characterising the hydrocarbon material recovered from the 61 g. of mixed picrates, m. p. *ca.* 140°. It boiled constantly at 228°/26 mm. and the m. p., originally 105—110°, slowly rose on crystallisation from alcohol to 111—113°; it then did not change further. The crystals were homogeneous, colourless flakes (Found: C, 93·6, 93·65; H, 6·8, 6·7. $C_{16}H_{12}$ requires C, 94·1; H, 5·9%. $C_{16}H_{14}$ requires C, 93·2; H, 6·8%. $C_{16}H_{16}$ requires C, 92·3; H, 7·7%) with composition intermediate between di- and tetra-hydropyrene. When admixed with pure 1 : 2-dihydropyrene, m. p. 132°, the m. p. was slightly raised and with pure *as*.-hexahydropyrene, m. p. 105°, slightly lowered. Reduction showed that it consisted essentially of these two hydrocarbons in close association either as mixed crystals or as a compound (1 or 2 mols. of dihydro- to 1 mol. of *as*.-hexahydro-pyrene). The hydrocarbon (14 g.), m. p. 111—113°, was dissolved in 500 c.c. of boiling amyl alcohol, and 14 g. of sodium added in pieces. The product was worked up as described in the reduction of pure 1 : 2-dihydropyrene (below) and consisted of non-picrate-forming hydrocarbons; the least soluble and highest melting was pure 1 : 2 : 6 : 7-tetrahydropyrene (2 g.) identical with the specimen obtained by catalytic hydrogenation. An intermediate fraction formed homogeneous colourless needles of constant m. p. 73°, but appeared to be deca- and tetra-hydropyrenes in close association (Found: C, 90·8; H, 8·7%). The liquid portion contained the two isomeric decahydropyrenes (see reduction of *as*.-hexahydropyrene, below) in a subfraction of b. p. 148—150°/2 mm. (Found: C, 90·9; H, 9·0%).

1 : 2 : 6 : 7-Tetrahydropyrene (IV) is very soluble in petrol, benzene or ether and crystallises from alcohol, in which it is moderately readily soluble, in thin colourless flakes, m. p. 138° (Found: C, 93·1; H, 6·9. $C_{16}H_{14}$ requires C, 93·2; H, 6·8%). It is rather more soluble in alcohol than *s*.-hexahydropyrene, m. p. 132°, but has no tendency to associate or form mixed crystals with the latter. When mixed with *s*.-hexahydropyrene, its m. p. is depressed to 99—110°, but with 1 : 2-dihydropyrene, m. p. 132°, only a slight depression to 130° is noticed. The hydrocarbon is dehydrogenated to pyrene by heating with selenium for 6 hours at 300°.

Reduction of Pyrene with Sodium and Amyl Alcohol.—Following Cook and Hewett (J., 1933, 404), 66 g. of sodium were added gradually to 650 c.c. of boiling amyl alcohol containing 40 g. of pyrene. When most of the sodium had been added, the mixture was frequently shaken in order to granulate the metal and increase its activity. When all the sodium had dissolved (4 hours), steam was passed to remove the amyl alcohol. The reduction product was extracted by ether from the cooled aqueous suspension and dissolved in boiling alcohol, to which 40 g. of picric acid were added. On cooling, a mixture of *s*.-hexahydropyrene and the picrate of *as*.-hexahydropyrene crystallised. Pure *s*.-hexahydride (9·5 g.) (II) was obtained by washing the mixed crystals repeatedly with cold alcohol. The alcoholic liquors were evaporated, and successive crops of the picrate of *as*.-hexahydride removed, until only picric acid crystallised. All the crude picrate was triturated with cold petrol (b. p. 40—60°), which extracted the non-picrate-forming hydrocarbons. These were recovered and, crystallised from alcohol, yielded 1·5 g. of *s*.-hexahydride, and a smaller amount of a more stable, apparently homogeneous, substance crystallising in colourless flakes, m. p. 63° (Found: C, 91·7, 91·9; H, 8·2, 8·4%). This is evidently composed of equal amounts of tetrahydropyrene and one or both of the isomeric decahydropyrenes (see below) in association as mixed crystals or a loose compound ($C_{16}H_{14}$,$C_{16}H_{20}$ requires C, 91·9; H, 8·1%).

The picrate (30 g., m. p. 143°) was decomposed by aqueous ammonia and gave 9 g. of pure *as*.-hexahydropyrene (VI) crystallising in flakes from alcohol, m. p. 106° (Found: C, 92·35; H, 7·6. Calc. for $C_{16}H_{16}$: C, 92·3; H, 7·7%).

Reduction of 1 : 2-*Dihydro*-, 1 : 2 : 6 : 7-*Tetrahydro*-, 3 : 4 : 5 : 8 : 9 : 10(s.)- *and* 1 : 2 : 3 : 4 : 5 : 12-(as.)-*Hexahydro-pyrenes.*—Reduction of all these derivatives with sodium and amyl alcohol and examination of the products were carried out on the same lines as described under pyrene, an essential step being treatment with picric acid and separation of any picrate-forming hydrocarbon.

(a) 1 : 2-*Dihydropyrene* (III). The hydrocarbon (0·5 g.) was treated with 0·75 g. of sodium. No isolable amount of picrate-forming substance was present. The non-picrate-forming product was recrystallised from alcohol and formed colourless flakes, m. p. 138°, identical with pure 1 : 2 : 6 : 7-tetrahydropyrene, isolated from the products of catalytic hydrogenation of pyrene. In the mother-liquors were substances melting below 100°, consisting of decahydro-

pyrenes due to the use of excess of sodium in the reduction. There was no sign of the formation of *s*.-hexahydropyrene, which under these conditions would not have been further reduced to any great extent.

(*b*) *1 : 2 : 6 : 7-Tetrahydropyrene : Preparation of 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-decahydropyrene* (V). The product obtained in good yield from 1 g. of hydrocarbon and 4 g. of sodium was at first an oil which did not form a picrate, but after distillation in a vacuum and crystallisation from alcohol, in which it was quite soluble, it formed colourless needles or elongated plates, m. p. 68°, of 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-*decahydropyrene* (V) (Found : C, 90·8; H, 9·0. $C_{16}H_{20}$ requires C, 90·6; H, 9·4%). When heated, this hydrocarbon had a faint terpene-like odour.

(*c*) *3 : 4 : 5 : 8 : 9 : 10-Hexahydropyrene* (*s*.)*: Preparation of 1 : 2 : 3 : 4 : 5 : 8 : 9 : 10 : 11 : 12-decahydropyrene* (VII). The hydrocarbon (3 g.) was treated with 30 g. of sodium and the product, solid and non-picrate-forming, was fractionally crystallised from alcohol. It yielded *ca*. 1 g. of pure and unchanged *s*.-hexahydropyrene, m. p. 132°, and an equal amount of a lower-melting substance, which was more soluble in alcohol, from which it separated in colourless flakes, m. p. 68°. This hydrocarbon, 1 : 2 : 3 : 4 : 5 : 8 : 9 : 10 : 11 : 12-*decahydropyrene* (VII) (Found : C, 90·5; H, 9·1%), is isomeric with the foregoing decahydride and on admixture the m. p. falls to 46°. In the mother-liquors was present an oily hydrocarbon product still richer in hydrogen, possibly " perhydropyrene " (Matsuno and Han, *loc. cit.*).

(*d*) 1 : 2 : 3 : 4 : 5 : 12-*Hexahydropyrene* (*as*.). The hydrocarbon (5 g.) was reduced with 20 g. of sodium; no picrate-forming fraction was found in the product, which was a colourless viscid oil. After distillation in a vacuum the fraction, b. p. 148—150°/2 mm., crystallised on cooling to 0°, but melted almost completely at room temperature. The low m. p. shows that it contains both the 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16- and the 1 : 2 : 3 : 4 : 5 : 8 : 9 : 10 : 11 : 12-decahydride (Found : C, 90·6; H, 9·2. Calc. for $C_{16}H_{20}$: C, 90·6; H, 9·4%). No attempt was made to separate them. The higher-boiling fractions contained a low-melting solid substance, forming homogeneous, colourless needles, m. p. 55°, when crystallised from alcohol and apparently composed of mixed crystals of deca- and hexa-hydropyrene (Found : C, 90·3; H, 8·9%).

Oxidation of 1 : 2-Dihydro-, 1 : 2 : 6 : 7-Tetrahydro-, 1 : 2 : 3 : 4 : 5 : 12-Hexahydro-, and 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-Decahydro-pyrenes.—(*a*) 1 : 2-*Dihydropyrene*. (i) *With hydrogen peroxide*. The hydrocarbon (1 g.) was dissolved in a little warm acetic acid and kept at about 100° during 6 hours, hydrogen peroxide solution (" 100 vols.") being added in small portions until no further colour changes occurred. The solution was then cooled, neutralised with sodium carbonate, extracted with ether to remove neutral material, made acid, and evaporated to dryness to remove acetic acid. From the residue ether extracted an acid substance (0·1 g.) which crystallised from acetone in cream flakes, m. p. 265°. Analysis showed this to be 9 : 10-*dihydrophenanthrene*-4 : 5-*dicarboxylic acid* (VIII) (Found : C, 71·7; H, 4·7. $C_{16}H_{12}O_4$ requires C, 71·8; H, 4·4%). The dihydropyrene is resistant to chromic acid in boiling acetic acid and some at least was recovered unattacked after 4 hours.

(ii) *With potassium permanganate*. The hydrocarbon (1 g.) was suspended in 400 c.c. of boiling water to which 30 g. of potassium permanganate were slowly added until no crystals of the hydrocarbon floated in the cooled solution (2 days). The excess of permanganate was then destroyed with hydrogen peroxide, and the boiling solution filtered from precipitated manganese dioxide, which was extracted three times with boiling water. The combined solutions, containing the potassium salt of the acidic oxidation product, were evaporated to small bulk, made acid, and thoroughly extracted with ether. A small amount of diphenyl-2 : 6 : 2′ : 6′-tetracarboxylic acid, forming iridescent flakes, m. p. 400°, identical in all respects with a specimen made synthetically from *m*-2-xylidine (below), was isolated by crystallisation of the crude acid oxidation product from acetone.

(*b*) 1 : 2 : 6 : 7-*Tetrahydropyrene*. Like the dihydropyrene, the tetrahydride (0·5 g.) was oxidised very slowly when heated with potassium permanganate (7·0 g.) in boiling aqueous suspension, but after 2 days no unchanged hydrocarbon remained and the acid oxidation product contained diphenyl-2 : 6 : 2′ : 6′-tetracarboxylic acid, which was isolated as described above and compared with an authentic specimen.

(*c*) 1 : 2 : 3 : 4 : 5 : 12-*Hexahydropyrene* (*as*.). Cook and Hewett (*loc. cit.*) remark that this hydrocarbon is resistant to alkaline permanganate, but it was found to have disappeared after boiling for 3 days in aqueous suspension with excess of potassium permanganate. The resinous acidic oxidation product was very small in amount and no crystalline individual substance could be isolated therefrom.

(*d*) 1 : 2 : 3 : 4 : 5 : 6 : 7 : 12 : 13 : 16-*Decahydropyrene*. The hydrocarbon (5·0 g.) was

suspended in boiling water and treated with 50 g. of potassium permanganate until none remained unoxidised. The acidic oxidation product, isolated as described, was small in amount and contained aliphatic acids in addition to resinous substances. No hemimellitic acid could be isolated.

*Preparation of 2-Bromo*iso*phthalic* (X) *and Diphenyl-2 : 6 : 2′ : 6′-tetracarboxylic Acids* (IX).—James, Kenner, and Stubbings (J., 1920, **117**, 774) obtained methyl diphenyl-2 : 6 : 2′ : 6′-tetracarboxylate by treating methyl 2-iodo*iso*phthalate with copper bronze, but the following process is more expeditious. A solution of *m*-2-xylidine (72 g.) in 72 c.c. of concentrated sulphuric acid and 360 c.c. of water was diazotised at 5—10° with an aqueous solution of 43 g. of sodium nitrite and poured into a cold solution of cuprous bromide (made by saturating 65 g. of potassium bromide and 130 g. of copper sulphate in 576 c.c. of water with sulphur dioxide) in 270 c.c. of hydrobromic acid (b. p. 125—127°). After decomposition at 100° the oily 2-bromo-*m*-xylene, purified by extraction with ether and by distillation from solid potassium hydroxide (yield, 27 g.; b. p. 200—201°), was suspended in 500 c.c. of boiling water and oxidised with 100 g. of potassium permanganate, added gradually. After the excess of permanganate had been destroyed, the solution was filtered from precipitated manganese dioxide, concentrated, cooled, acidified, and extracted with ether. The acid product (24·5 g., m. p. 212°) obtained after removal of the ether contained 2-bromo*iso*phthalic acid contaminated with 22% of 2-hydroxy*iso*phthalic acid. The mixed methyl esters, obtained by saturating a solution of the acid product in dry methanol with hydrogen chloride and distilling, boiled at 188°/20 mm. (yield, quantitative). Pure *methyl 2-bromo*iso*phthalate* was obtained, by shaking the mixture in ethereal solution with cold dilute caustic soda solution and water, as a colourless liquid, b. p. 190—191°/22 mm., which did not set on keeping (Found: Br, 29·1. $C_{10}H_9O_4Br$ requires Br, 29·3%). It was hydrolysed quantitatively by 2 hours' boiling with concentrated hydrochloric acid; *2-bromo*iso*phthalic acid* (X), m. p. 218°, crystallised in colourless needles on cooling (Found: Br, 32·7. $C_8H_5O_4Br$ requires Br, 32·7%).

When methyl 2-bromo*iso*phthalate (5 g.) was heated with 2 g. of copper bronze, a vigorous reaction began at 180°. After being kept at 200° for ½ hour, the product was cooled and extracted with ether. From this extract, 2 g. of methyl diphenyl-2 : 6 : 2′ : 6′-tetracarboxylate, m. p. 124—125°, were obtained. On hydrolysis this gave the acid, quantitatively, in colourless flakes, m. p. 400°. When the acid melts, it decomposes and a yellow sublimate, m. p. 225°, appears. A further property useful in characterisation is the sparing solubility in ether.

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265. *The Nature of the Solid Carbon–Oxygen Complex. Part I. The Oxidative Action of Graphitic Oxide and Active Carbon plus Oxygen on some Aromatic Amines.*

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Carbon and oxygen can be associated in the solid phase in (*a*) graphitic oxide, (*b*) the substance formed when active carbon combines with oxygen, and (*c*) C_xO_y, the intermediate oxide formed during carbon combustion, the existence of which was originally suggested by Rhead and Wheeler (J., 1912, **101**, 846; 1913, **103**, 461). The following facts suggest that there are close chemical and physical similarities between these three substances. (*a*) On thermal decomposition, graphitic oxide yields carbon monoxide and dioxide, but no free oxygen. Berthelot and Petit (*Compt. rend.*, 1890, **110**, 101) obtained a CO : CO_2 ratio of 3 : 2 in the thermal decomposition of graphitic oxide prepared from kish. Kohlschütter and Haenni (*Z. anorg. Chem.*, 1919, **105**, 121) reported CO : CO_2 ratios of 1·54—2·04, according to the method of decomposition. (*b*) Only a very small part of the oxygen adsorbed by active charcoal can be removed by evaporation at ordinary temperatures. On raising the temperature it is evolved as oxides of carbon. (*c*) The balance of evidence appears to

be in favour of the view that carbon monoxide and dioxide are formed simultaneously in the primary reaction during the combustion of carbon (Riley, *J. Inst. Fuel*, 1937, **10**, 149). (*d*) The metallic electrons of the graphite crystal lattice are concerned in the bonding of the oxygen in graphitic oxide, for Hofmann and his co-workers (*Annalen*, 1934, **510**, 1) have shown that the latter is a non-conductor of electricity. (*e*) Siebel (*Z. Physik*, 1931, **4**, 288) found that the electrical resistance of carbon is slightly increased by simple exposure to air, suggesting that here again the metallic electrons are concerned in the adsorption of oxygen. (*f*) Meyer (*Z. physikal. Chem.*, 1932, *B*, **17**, 385) has shown that when a graphite filament adsorbs oxygen at high temperatures its electrical conductivity decreases. (*g*) The temperature at which graphitic oxide decomposes rapidly depends upon the method of heating. Kohlschütter and Haenni (*loc. cit.*) obtained decomposition (" verpuffen ") temperatures varying from 134° to 193° according to the rapidity of the heating. (*h*) Berl and Weingärtner (*Z. physikal. Chem.*, 1932, *A*, **161**, 315) reported an ignition temperature as low as 215° for a sample of activated beechwood charcoal, *i.e.*, one free from appreciable amounts of volatile matter. (*i*) Hofmann and co-workers (*loc. cit.*) have shown by means of *X*-rays that the oxygen atoms in graphitic oxide are bonded between the layer planes of the graphite crystal lattice (see also Balfour, Riley, and Robinson, J., 1936, 456). (*j*) The concept of the mesomorphous state of active carbons (Berl, Andress, Reinhardt, and Herbert, *Z. physikal. Chem.*, 1932, *A*, **158**, 273; Berl and Reinhardt, *ibid.*, 1933, *A*, **166**, 81) and the fact that in very small graphite crystallites the hexagon planes become further apart (Randall and Rooksby, *Nature*, 1932, **129**, 280) indicate that the hexagon-plane surfaces in active carbons may be accessible to molecular oxygen at ordinary temperatures. (*k*) Boersch and Meyer (*Z. physikal. Chem.*, 1935, *B*, **29**, 59) have shown by means of electron rays that the graphite crystal lattice expands, concertina-like, along the *C*-axis when it is exposed to oxygen at high temperatures (700—950°) (see also Eucken, *Z. angew. Chem.*, 1930, **43**, 986).

Lowry and Hulett (*J. Amer. Chem. Soc.*, 1920, **42**, 1408) suggested that a solid surface oxide of carbon, perhaps similar to Brodie's graphitic oxide, plays an important intermediate part in the combustion of carbon.

The above considerations led us to undertake the following experiments with a view to learn something of the chemical nature of the oxygen present in graphitic oxide. Any knowledge gained in this direction has an important bearing upon the complex problems associated with the combustion of carbon. Preliminary experiments indicated that a study of the oxidative action of graphitic oxide on aniline and mono- and di-methylanilines would yield interesting results. The procedure adopted was simple: excess of the amine was warmed with graphitic oxide on the water-bath under reflux until the reduction of the oxide was more or less complete. The following products were obtained: (a) *From pure aniline*: azophenine (2 : 5-dianilino-*p*-benzoquinonedianil), and a dye of the mauveine type. (b) *From commercial aniline* (containing *o*- and *p*-toluidine): a rosaniline dye, in addition to the above products. (c) *From methylaniline*: *NN'N''*-trimethylrosaniline, probably containing some less highly methylated homologues, and a complex uncrystallisable resinous material, which on distillation gave a complex uncrystallisable viscous oil. (d) *From dimethylaniline*: methyl-violet (as sulphate), leuco-crystal-violet (4 : 4' : 4''-trisdimethylaminotriphenylmethane) and 4 : 4'-bisdimethylaminodiphenylmethane. The triphenylmethane dyes produced in these oxidations were sulphates, the sulphate ion being provided by the sulphuric acid occluded in the graphitic oxide. The formation of azophenine in the oxidation of pure aniline indicated that the methane carbon atom in the phenylmethane compounds produced in the other experiments was not derived from the graphitic oxide but probably from the methyl group in *p*-toluidine in the case of the rosaniline, and from one of the amine methyl groups in the case of the other compounds. This view is supported by the observation of E. and O. Fischer (*Ber.*, 1878, **11**, 2099) that dimethylaniline heated with lead dioxide in dilute sulphuric acid solution at 30—40° gave formaldehyde and crystal-violet.

The formation of azophenine in the oxidation of aniline and of the di- and tri-phenylmethane bases in the oxidation of dimethylaniline shows that the amine hydrogen atoms play an important part in the reaction. The formation of highly complex products from

monomethylaniline can perhaps be explained by the possibility of the occurrence in this case of both the azophenine type and the hydrocarbon base type of reaction. Von Braun (*Ber.*, 1908, **41**, 2147) has described the preparation of 4 : 4'-bismethylaminodiphenylmethane by condensing methylaniline with formaldehyde, and it is of interest that in this reaction a considerable amount of complex resinous material was formed.

An attempt was made to calculate an oxygen balance in these reactions. This was difficult, for the exact mechanisms of the reactions involved were not known. In the case of aniline the yields of azophenine and pseudo-mauveine-type of compound accounted for approximately 40% of the active oxygen present in the graphitic oxide as estimated volumetrically by means of ferrous sulphate. In the dimethylaniline oxidation the yields of methyl-violet, leuco-crystal-violet and 4 : 4'-bisdimethylaminotriphenylmethane accounted for approximately 30% of the active oxygen. No estimate could be made of the oxygen remaining in the residual carbon : the presence of some was shown by the fact that the carbon on being dried and heated decrepitated slightly.

When aniline is oxidised by the reagents mentioned, the following products are obtained : hydrogen peroxide or sodium peroxide in dilute acetic acid, 2 : 5-dianilinobenzoquinonemonoanil (Schunk and Marchlewski, *Ber.*, 1892, **25**, 3574) : sodium peroxide and stronger acids, aniline-black (Fischer and Trost, *ibid.*, 1893, **26**, 3083) ; hydrogen peroxide in neutral solution, benzene, azobenzene, and a little nitrobenzene (Bamberger and Tschirner, *ibid.*, 1898, **31**, 1523) ; neutral persulphate, 2 : 5-dianilinobenzoquinonemonoimide (Caro, *Z. angew. Chem.*, 1898, **11**, 848 ; Willstätter and Majima, *Ber.*, 1910, **43**, 2590) ; ammonium persulphate, aniline-black (Börnstein, *Ber.*, 1901, **34**, 1286 ; Willstätter and Dorogi, *ibid.*, 1909, **42**, 4126) ; permonosulphuric acid, nitrobenzene and phenylhydroxylamine (Bamberger and Tschirner, *ibid.*, 1899, **32**, 1675) ; lead dioxide on aniline vapour, phenazine (Schichutzki, *ibid.*, 1874, **7**, 1454) ; lead dioxide on a neutral aniline solution at 100°, 2 : 5-dianilino-*p*-benzoquinoneimidanil, azophenine, and a little azobenzene (Börnstein, *loc. cit.* ; Majima and Aoki, *Ber.*, 1911, **44**, 3080 ; Goldschmidt, *ibid.*, 1920, **53**, 34 ; Goldschmidt and Wurzschmitt, *ibid.*, 1922, **55**, 3221) ; lead dioxide in sulphuric acid, quinone and intermediates in aniline-black formation (Willstätter and Dorogi, *ibid.*, 1909, **42**, 2155).

Peroxides and lead dioxide in very weakly acid or neutral solutions thus oxidise aniline to iminoquinone derivatives. The fully condensed azophenine is only obtained in quantity by the use of lead dioxide. The above experiments thus indicate that graphitic oxide is similar in its action as an oxidising agent to lead dioxide and to hydrogen peroxide, and it can be concluded that the oxygen in graphitic oxide is present at a potential similar to that of the oxygen in these compounds.

The formation of leuco-crystal-violet and 4 : 4'-bisdimethylaminodiphenylmethane in the oxidation of dimethylaniline is somewhat surprising, particularly when methyl-violet is simultaneously produced. The formation of the latter is intimately connected with the presence of occluded sulphuric acid in the graphitic oxide (see below). Careful examination of the reaction product failed to reveal the presence of the carbinol base. Hitherto, leuco-crystal-violet has been prepared by various condensation reactions, *e.g.*, that of dimethylaniline with orthoformic ester (Fischer and Körner, *ibid.*, 1884, **17**, 99) or with dichloroguanidine (Gatterman and Schnitzpahn, *ibid.*, 1898, **31**, 1774) ; or by the action of various reducing agents on the crystal-violet carbinol base, *e.g.*, tin and hydrochloric acid (Wichelhaus, *ibid.*, 1881, **14**, 1952 ; 1883, **16**, 2007), followed by alkali. Similarly, 4 : 4'-bisdimethylaminodiphenylmethane may be prepared by the reduction of Michler's ketone (Nathansohn and Müller, *ibid.*, 1889, **22**, 1882) or by various condensation reactions with dimethylaniline (Cohn, *Chem.-Ztg.*, 1900, **24**, 564 ; Doebner, *Ber.*, 1879, **12**, 812 ; Hanimann, *ibid.*, 1877, **10**, 1235). Neither has hitherto been produced by a direct oxidation such as that with graphitic oxide.

Both these bases, in the cold in dilute acid solution, are immediately oxidised to the brightly coloured salts of their respective carbinol bases on the addition of a little lead or manganese dioxide. The addition of graphitic oxide to the dilute acid solution did not give the coloured salt, even on prolonged boiling. It is perhaps significant that hydrogen peroxide also does not convert the hydrocarbon bases into the coloured carbinol salts, even

when boiled with them in acid solution. This may be a solvent effect, as the oxidising properties of graphitic oxide are not so marked in presence of excess of water. This result, however, appears to offer some experimental support for the suggestion (Balfour, Riley, and Robinson, *loc. cit.*; cf. Hofmann, Frenzel, and Csalán, *loc. cit.*) that the oxygen in graphitic oxide is peroxidic in character, although perhaps it is not legitimate to compare the behaviour of aqueous hydrogen peroxide with the oxidative activity of a solid complex like graphitic oxide.

The above experiments indicate that, in certain cases, graphitic oxide might prove a useful oxidising agent. The temperature at which it will act depends upon the nature of the substance oxidised. Heated alone, it commences to decompose at temperatures as low as 130—140°. The carbon formed in its decomposition is decidedly active (Lowry and Morgan, *J. Physical Chem.*, 1925, **29**, 1105). This might be advantageous in certain circumstances.

A series of parallel experiments, employing air in the presence of active charcoal as the oxidising agent, were also carried out. A few grams of active charcoal granules were added to the amine, and air was bubbled through the mixture for several hours whilst it was heated on the water-bath. The most striking results were obtained with the methylanilines. Dimethylaniline gave leuco-crystal-violet and 4 : 4'-bisdimethylaminodiphenylmethane. When the active charcoal was previously treated with dilute sulphuric acid, or if a little acid was added to the amine, methyl-violet was also produced. Monomethylaniline gave a complex uncrystallisable resin, similar to that obtained with the graphitic oxide. When an acid-treated charcoal was used, the triphenylmethane dye was also obtained. This striking parallelism between the oxidative activity of graphitic oxide and of oxygen in the presence of active carbon can leave little doubt as to the fundamental similarity between graphitic oxide and the active carbon–oxygen complex. It is noteworthy in this connection that Kade and Ignatjew (Russ. P. 23917, 13/10/1931) observed the formation of methyl-violet when hot air was passed through a solution of dimethylaniline and phenol in the presence of activated wood charcoal and sodium chloride.

The parallelism in the case of aniline is not quite so close. With active charcoal (both acid and neutral) and oxygen, tarry products were formed at 100°, from which only small quantities of impure crystalline products could be isolated. These could not be definitely identified, but their colour reactions with concentrated sulphuric acid indicated that they were iminoquinone derivatives. On using a sulphuric acid-treated charcoal at the b. p. of aniline, a small amount of azophenine and a few grams of some substance, probably closely allied to induline-3B, were formed. Some rosaniline was also formed when an acid-treated active carbon was employed with a synthetic mixture of aniline and *o*- and *p*-toluidine.

This difference in the behaviour of graphitic oxide and oxygen + active carbon is due perhaps to some subtle difference in these substances, or perhaps to the fact that aniline is oxidised to tarry products at an appreciable velocity by oxygen alone. The above experiments, together with the work of Hofmann *et al.* (*loc. cit.*) on the structure of graphitic oxide and of Berl *et al.* (*loc. cit.*) on active carbons, offer convincing evidence that when carbon reacts with or adsorbs oxygen the latter may, in certain circumstances, penetrate between the hexagon layer planes of the graphite crystallites.

EXPERIMENTAL.

Preparation of Graphitic Oxide.—Finely divided Ceylon graphite (10 g.) was added to a mixture of concentrated sulphuric acid (300 c.c.) and concentrated nitric acid (150 c.c.; *d* 1·4) in a litre bolt-head flask. The mixture was stirred automatically, and potassium chlorate (200 g.) added in small portions during 4—6 hours. Chlorine dioxide was prevented from accumulating over the liquid, and exploding, by drawing a rapid current of air through the flask by means of a tube, one end of which was placed just above the surface of the reaction mixture and the other end connected to a filter-pump. After the addition of the chlorate, the reaction mixture was poured into 2 l. of water, the green product, which still contained some unchanged carbon, was washed three times by decantation, filtered off, pressed as dry as possible, and again treated with the concentrated acids and potassium chlorate. After 2—3 hours' stirring it was

left overnight. The pale green glistening leaflets so produced were washed four times by decantation with tap water, which removed solid potassium chlorate, chloride, etc., and then 6—8 times with distilled water. The supernatant liquid then contained a fairly stable dispersion of graphitic oxide which would not settle completely within a week. Experience showed that further washing peptised the whole mass, and it was therefore filtered off at this stage and pressed as dry as possible. It was then shaken with and filtered from about 1 l. of dry alcohol thrice, and dried at 60° in an air-oven. During washing, the graphitic oxide became light yellow and then darkened somewhat. The product was light brown. It contained about 10% of available oxygen, as estimated by ferrous sulphate, and small amounts of adsorbed sulphate and chloride. A repetition of the above chlorate treatment would probably have increased the available oxygen, but owing to the pronounced hydrophilic nature of the substance, it was found expedient to oxidise it only twice.

Oxidation of Aniline.—" AnalaR " Aniline (250 c.c.) was heated in a conical flask under a reflux condenser with graphitic oxide (50 g.) for 20 hours on the water-bath. The graphitic oxide was then almost completely reduced, for a little of it deflagrated only slightly on being heated in the Bunsen flame. The reaction product was thoroughly extracted in a large Soxhlet apparatus with 2 l. of benzene followed by rectified spirit. The benzene was removed from the first extract by distillation, and excess of aniline recovered by distillation under reduced pressure, or by steam-distillation. A tarry solid remained, which all dissolved on warming in 500 c.c. of benzene, and the solution on standing deposited reddish-brown crystals which, on recrystallisation from benzene and light petroleum alternately, yielded brick-red crystals of azophenine (2 : 5-dianilino-*p*-benzoquinonedianil), m. p. 246—247°. Further crops of these crystals were obtained from the mother-liquors; total yield 7·1 g. (Found : C, 81·8; H, 5·6; N, 13·1. Calc. : C, 81·8; H, 5·5; N, 12·8%). In hydrochloric acid suspension the crystals became violet, and a characteristic violet solution was obtained in concentrated sulphuric acid, which on dilution became blue and developed a carmine fluorescence (Witt and Thomas, J., 1883, **43**, 115). Exhaustive examination of the benzene-soluble fraction showed that no appreciable quantity of any other compound was present, apart from small amounts of tar and some acetone-soluble material.

The rectified spirit extract on concentration deposited 2·8 g. of a dark blue solid, insoluble in the commoner organic solvents except alcohol. It was slightly soluble in water and gave purple solutions. With sulphuric acid it gave in the cold a dirty olive-green solution, which became blue on slight dilution and purple on further dilution, indicating that the substance was probably pseudo-mauveine or a closely allied compound (Fischer and Hepp, *Annalen*, 1893, **273**, 315). Owing to the presence of tarry impurities, and possibly also of the sulphate ion, this compound could not be purified by recrystallisation. Some aniline-black was possibly left in the residual carbon.

When ordinary commercial aniline (containing *o*- and *p*-toluidine) was used, the alcoholic extract was much redder, and on evaporation a red, tarry oil was obtained which, when boiled with water, gave a bright red solution which dyed wool directly, the colour being fast to water. On the addition of hydrochloric acid, the solution became pale yellowish-green, and the original colour was restored on neutralisation. Excess of caustic alkali destroyed the colour, rapidly on warming slightly, a white precipitate being formed. The colour was again restored on neutralisation. The bright red solution was bleached rapidly by zinc and hydrochloric acid, and the colour was not restored in air. From these reactions and by analogy with the behaviour of graphitic oxide with the other amines studied, it was concluded that the bright red colour was due to the presence of pararosaniline and closely allied dyes. The acid necessary for the formation of these dyes was provided by the sulphuric acid occluded in the graphitic oxide. When, instead of aniline, a synthetic mixture of aniline and *p*-toluidine was used, on oxidation a red colour developed in a few minutes in a manner similar to that in which methyl- and dimethyl-aniline developed purple and violet colours respectively.

Oxidation of Dimethylaniline.—The dimethylaniline was freed from methylaniline by treatment with acetic anhydride and distillation, the fraction, b. p. 191—193°, being collected. It was treated with graphitic oxide exactly as above but for only 15 hours. The product, which had become intensely violet, was extracted with light petroleum (1½ l.) (Soxhlet), and then by a similar amount of rectified spirit. The brown light petroleum extract was freed from solvent by distillation, and from excess of amine by distillation under reduced pressure. The tarry residue crystallised on standing for 2 days. The crystals were washed with a little ether, becoming white with a bluish-green tinge. The total yield was 21 g. The crystals were soluble in most organic solvents. Repeated recrystallisation from alcohol raised the m. p. from 85°

to 172—174°, the mother-liquors becoming pink in the process. As recrystallisation proceeded, it became obvious that two substances were present, and their separation was effected by slow crystallisation from light petroleum, white needles (1—2 mm. long) and clusters of pale yellow prisms (1 cm. long) being formed. These were separated by hand picking and purified by further recrystallisation from alcohol and light petroleum. From alcohol, the needles formed nacreous plates, m. p. 176°, of leuco-crystal-violet (*4 : 4′ : 4″-trisdimethylaminotriphenylmethane*) (Found : C, 80·6; H, 8·5; N, 11·4. Calc.: C, 80·4; H, 8·3; N, 11·3%). With methyl iodide in methyl-alcoholic solution it gave a methiodide, m. p. 187—188°. A light petroleum solution of the hydrocarbon base was poured on filter-paper, and on evaporation and exposure to air the paper developed an intense violet colour. This reaction was accelerated by exposure to light.

The long prisms had m. p. 91—92°, undepressed on admixture with authentic 4 : 4′-bisdimethylaminodiphenylmethane (Found: C, 80·6; H, 8·8; N, 11·2. Calc.: C, 80·3; H, 8·7; N, 11·0%). The final yields of the pure products were: leuco-crystal-violet 8 g. ; 4 : 4′-bisdimethylaminodiphenylmethane 7 g.

The deep violet alcoholic extract of the reaction mixture was evaporated to dryness, and the residue recrystallised from water. A further crop of crystals was salted out from the mother-liquors, in all 4·3 g. being obtained. The crystals had the characteristic green sheen and all the other properties of a triphenylmethane dyestuff. The dye was substantive to wool, the dyed wool being stripped by a solution of hydrochloric acid in boiling dilute alcohol. The substance contained a sulphate ion. The above and several other tests left little doubt that the product was methyl-violet in the form of its sulphate. It was somewhat less soluble than commercial crystal-violet, which is a chloride. The source of the sulphate ion was the sulphuric acid adsorbed by the graphitic oxide. It was possible that the substance isolated contained a small amount of incompletely methylated analogues.

No other compound could be isolated from the alcoholic extract, or on further extraction of the residual carbon with various solvents.

Oxidation of Methylaniline.—The reaction was carried out as for the dimethyl-base. The reaction mixture, which had become deep purple, was thoroughly extracted (Soxhlet) with light petroleum, followed by alcohol. The first extract was deep brown, and the second deep purple. The latter was evaporated to dryness, the residue washed with ether to remove tarry products and then recrystallised from water, crystals (3·1 g.) with a green lustre, very similar to crystal-violet, being obtained. Its reactions showed it to be a triphenylmethane dye, and by analogy with crystal-violet it was concluded that it was *NN′N″*-trimethylpararosaniline, which probably contained a small amount of less highly methylated analogues. It dyed wool with a shade intermediate between those of crystal-violet and of rosaniline.

The light petroleum extract was worked up as for dimethylaniline. A strong smell of carbylamine was noticed. (Excess of methylaniline was also removed by steam distillation.) The residue in the flask (about 30 c.c.) on cooling set to a hard, brown, vitreous, resin-like mass. Attempts to crystallise this from various solvents gave only flocculent, dark brown precipitates. The resin was therefore distilled at 1 mm. pressure. A turbid orange-coloured oil commenced to distil at 90°, and this became darker and more viscous as distillation proceeded. Nothing further distilled above 260°. Redistillation gave no constant-boiling or crystalline fraction. Attempts to prepare a picrate, methiodide, benzoyl derivative, ferric chloride compound, and nitroso-compound all failed. It was thus concluded that in addition to the triphenylmethane dye, the product of oxidising methylaniline with graphitic oxide was a complex resinous material.

Preparation of Active Charcoal.—The charcoal (quality 75; NL 13) was provided by Messrs. Sutcliffe, Speakman & Co., to whom the authors express their thanks. It was reactivated as follows in order that the graphitic crystallites should be reduced to very small dimensions. The charcoal, contained in a porcelain boat, was heated at 900° in a large silica tube furnace in a stream of dry carbon dioxide, and the degree of activation expressed as a percentage loss in weight. For some of the experiments the activated charcoal was soaked in dilute sulphuric acid for 2 days, drained, and dried at 100°.

Oxidation of Aniline.—Activated (22·5%) charcoal granules were packed in a vertical tube surrounded by an electric furnace and connected at the lower end to a 200-c.c. bolt-head flask and at the upper end to a reflux condenser. Aniline (100 c.c. "AnalaR") was placed in the flask and heated to boiling, and a slow stream of oxygen bubbled through it. The charcoal was kept at 100° by means of the electric furnace. The aniline turned black, and there was a strong odour of carbylamine in the initial stages. After 8 hours, the dark viscous product was filtered and distilled in a vacuum. The residual charcoal was extracted with benzene, and the extract freed from solvent by evaporation. The residues were principally uncrystallisable tars

but small amounts of two substances, probably of the mauveine and azophenine type, were isolated. They were too small for purification and identification, but gave characteristic colour reactions.

Aniline (100 c.c. "AnalaR") was boiled under a reflux with activated (40%), acid-treated carbon granules (10 g.) whilst a slow stream of oxygen was bubbled through the liquid. After 40 hours, excess of aniline was removed by steam-distillation, and the residue was extracted (Soxhlet) first with benzene and then with alcohol. From the benzene extract, 2 g. of a dark brown tarry solid were obtained which, on repeated recrystallisation from benzene, yielded a small amount of impure azophenine, m. p. 235°, mixed m. p. 241°. It gave the characteristic colour reaction with concentrated sulphuric acid. A tarry, bluish-brown solid was obtained from the benzene mother-liquors. Although it was not possible to purify this substance completely, its solubility in various solvents and its colour reaction with concentrated sulphuric acid (Fischer and Heiler, *Ber.*, 1893, **26**, 384) indicated it to be a compound of the induline type.

The alcoholic extract was deep violet, and on cooling deposited 3 g. of a dark blue powder. This was insoluble in toluene, light petroleum, and cold benzene, slightly soluble in boiling benzene, giving a pale pinkish solution, soluble in alcohol, acetone, and methyl alcohol, giving bluish-violet solutions. It dissolved in aniline, giving a violet solution, and in concentrated sulphuric acid, giving a blue colour. A piece of wool dipped into the alcoholic solution was dyed blue. On immersion in sulphuric acid, the fibre became almost colourless and the solution blue. The compound contained sulphate ion. The free base, liberated by adding caustic soda to the hot alcoholic solution, was obtained as a dark blue flocculent precipitate, which on recrystallising from benzene gave minute crystals with a faint metallic lustre. They softened at 245° but did not melt below 300° (Kehrmann, *Ber.*, 1923, **56**, 2936). These results indicated that at the higher temperature employed condensation had proceeded further than in the other aniline oxidations and that the blue product was probably a mixture of sulphates of compounds of the induline type.

Oxidation of Aniline containing o- *and* p-*Toluidine.*—Acid-treated, activated (40%) charcoal (9 g.) was added to a mixture of aniline (40 c.c.), *o*-toluidine (30 c.c.) and *p*-toluidine (12 c.c.). The mixture was heated under reflux on a water-bath for 40 hours whilst a current of air was bubbled through it. The charcoal was filtered off and extracted with benzene (Soxhlet), giving a reddish-brown solution. The solvent was distilled off, and the residual liquid added to the original filtrate. Excess of amines was removed by steam-distillation, and a brown tar and a red aqueous solution remained. The red solution gave all the characteristic reactions of a rosaniline, and the tar probably contained compounds of the azophenine type, but these could not be isolated in the pure state.

The charcoal was further extracted with alcohol, and a deep reddish-purple solution was obtained which deposited amine sulphates on cooling. Qualitative reactions showed that the solution probably contained a rosaniline dye and a compound of the mauveine type, although it was not possible to isolate sufficient of these substances in the pure state for definite identification.

Oxidation of Dimethylaniline.—Purified dimethylaniline (100 c.c.) was oxidised by gaseous oxygen in the presence of acid-treated, activated (40%) charcoal (50 g.) in the apparatus employing the electric furnace described above. A vigorous reaction occurred, and the amine rapidly darkened. After ½ hour the apparatus was allowed to cool in a stream of oxygen. After several minutes' cooling, a violent explosion occurred which shattered the reaction flask. Subsequent experiments were therefore carried out with air below 100°.

Activated (40%) charcoal granules (20 g.) were placed in a flask fitted with a reflux condenser, and dimethylaniline (100 c.c.) added. A slow current of air was bubbled through the reaction mixture for 20 hours whilst the flask was heated on the water-bath. Excess of amine was then removed by distillation under reduced pressure, and the solid residue recrystallised from light petroleum. The product obviously contained two sets of crystals, which were separated by hand picking. After further recrystallisation from light petroleum, two pure fractions were obtained. One (0·9 g.) consisted of pale yellowish prisms of 4 : 4'-bisdimethylaminodiphenylmethane, m. p. and mixed m. p. 90—91°, and the other (0·35 g.) of white needles of leuco-crystal-violet, m. p. and mixed m. p. 175—176°.

The experiment was repeated with dimethylaniline (100 c.c.) and activated (40%), acid-treated charcoal (20 g.). The air oxidation was continued for 40 hours. The resulting deep violet liquid was filtered, and excess dimethylaniline distilled off under reduced pressure. The residual liquid together with the carbon were extracted with light petroleum, and the resulting brown solution on evaporation yielded 0·6 g. of a crude mixture of leuco-crystal-violet and 4 : 4'-bisdimethylaminodiphenylmethane. The residual carbon was further extracted with

methylated spirit, and 7·3 g. of crude methyl-violet were isolated from the solution. This was purified by recrystallisation from water.

A further oxidation, in which sulphuric acid was added directly to excess of amine instead of to the charcoal, gave methyl-violet as the principal product.

Oxidation of Methylaniline.—Methylaniline (100 c.c.) was oxidised by air in the presence of activated (40%) carbon granules (20 g.) at 100° for 40 hours in the manner described above. Excess methylaniline was removed by distillation, and the residual carbon extracted first by light petroleum and then by alcohol. The first extract yielded an uncrystallisable oil similar to that obtained in the graphitic oxide oxidation, and the alcoholic extract yielded no appreciable quantity of any product. The experiment was repeated, sulphuric acid-treated charcoal being used. The liquid became very viscous and dark reddish-purple. After removal of excess methylaniline by distillation under reduced pressure, the residue and charcoal were first extracted with light petroleum, a dark brown uncrystallisable liquid being obtained, and then with alcohol, which gave a deep purple solution from which a purple solid, probably impure *NN'N''*-trimethylpararosaniline sulphate, was obtained.

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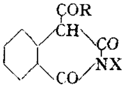
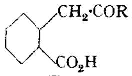
266. *Some Derivatives of Homophthalimide.*

By Robert D. Haworth.

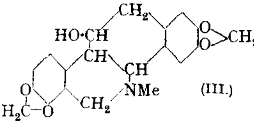
The reactivity of the methylene group of homophthalimide allows of facile condensation with aldehydes, diazotates, and alkyl halides, and it has now been shown that, in the presence of alkalis, reaction readily occurs with a variety of acid anhydrides or chlorides. The 4-monoacyl derivatives (I; X = H) are readily soluble in alkali, and the structure is established by the conversion of the benzoyl derivative (I; $R = C_6H_5$, X = H) into *o*-carboxybenzyl phenyl ketone (II), and confirmed by the preparation of a series of similar products (I; X = Me) from 2-methylhomophthalimide.



(I.)



(II.)



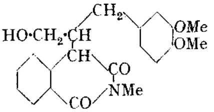
(III.)

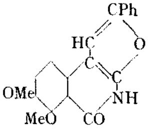
The phenylacetyl derivatives (I; $R = C_6H_5{\cdot}CH_2$, X = Me) were of interest as offering a possible method for the synthesis of alkaloids of the chelidonine type (III) (Bruchhausen and Bersch, *Ber.*, 1930, **63**, 2520; 1931, **64**, 947; Späth and Kuffner, *Ber.*, **1931**, **64**, 370, 1123, 2034), and the route was particularly attractive, as substituted homophthalic acids of appropriate orientation for the alkaloidal synthesis are available (Haworth, Perkin, and Stevens, J., 1926, 1769; Haworth, Koepfli, and Perkin, J., 1927, 551). Such phenylacetyl derivatives are readily prepared, but cyclisation experiments have been unsuccessful, in spite of the fact that favourable cases, such as those in which R is 3 : 4-dimethoxyphenyl or 3 : 4-methylenedioxyphenyl, have been investigated. Compounds of type (I; $R = C_6H_5{\cdot}CH_2$, X = Me) are quantitatively converted into 2-methylhomophthalimide and methyl phenylacetate by warming with methyl-alcoholic hydrogen chloride and the cyclisation failures are probably to be ascribed to the instability of substances of type (I) towards acidic reagents.

The condensation of ω-bromoacetophenone with 2-methylhomophthalimide gave the 4 : 4-diphenacyl derivative. The formation of 2 : 4 : 4-trialkyl derivatives by the action of alkylating agents on 2-methylhomophthalimide is in accordance with general experience

(Gabriel, *Ber.*, 1886, **19**, 2364; 1887, **20**, 1199; Haworth, Perkin, and Pink, J., 1925, **127**, 1710) and the preparation of 2 : 4-dialkylhomophthalimides presents considerable difficulties. It has been shown that the phenylacetyl derivative (I; R = $C_6H_5{\cdot}CH_2$, X = Me) can be converted into the *4-monomethyl derivative*, which on hydrolysis with methyl-alcoholic hydrogen chloride yields 2 : 4-dimethylhomophthalimide, and the method should prove generally useful for the preparation of 2 : 4-dialkylhomophthalimides.

2-Methylhomophthalimide condenses with *O*-methyleugenol oxide, yielding a *compound*, probably (IV), but preliminary cyclisation experiments were discouraging. An attempt has been made to utilise opianic acid in the synthesis of alkaloids of the chelidonine class. Potassium cyanide and 6 : 7-dimethoxy-3-phenacylphthalide (Goldschmidt, *Monatsh.*, 1891, **12**, 476) reacted to give an oil, which was converted by warm concentrated hydrochloric acid into a yellow crystalline *compound*, $C_{19}H_{15}O_4N$, for which structure (V), based on its neutral nature and analysis, is suggested, but as potassium cyanide did not react with 6 : 7-dimethoxy-3-(3′ : 4′-dimethoxyphenacyl)phthalide, this line of attack was abandoned.

(IV.) 

 (V.)

Most of the experiments described in this communication were carried out in 1932, and the publication of the results appears desirable, as experiments with a similar objective have reached a more advanced stage in the Oxford laboratories (see Richardson, Robinson, and Seijo, this vol., p. 835).

Experimental.

General Methods for Preparation of Compounds of Type (I).—(a) The appropriate acid chloride or anhydride (1·1 mols.) was added with cooling and stirring to a solution of homophthalimide or 2-methylhomophthalimide (1 mol.) in 5% potassium hydroxide solution (1·1 mols.). After 1½ hours, the product was collected and washed with water. (b) In some cases excess of 5% potassium hydroxide solution (2·5 mols.) was employed; after 2 hours, the product was liberated by acidification of the filtered solution, collected, and washed.

4-Acetyl-2-methylhomophthalimide (I; R = X = Me), obtained in 70% yields from acetic anhydride by method (a), crystallised from methyl alcohol in long needles or stout prisms, the latter form being favoured by slow crystallisation. Both forms melted at 113° (Found : C, 66·2; H, 5·2. $C_{12}H_{11}O_3N$ requires C, 66·3; H, 5·1%).

4-Benzoyl-2-methylhomophthalimide (I; R = C_6H_5, X = Me), obtained in 75% yields from benzoyl chloride by method (a), crystallised from methyl alcohol in long, pale yellow needles, m. p. 114—115° (Found : C, 72·9; H, 4·5. $C_{17}H_{13}O_3N$ requires C, 73·1; H, 4·7%).

4-Phenylacetyl-2-methylhomophthalimide (I; R = $C_6H_5{\cdot}CH_2$, X = Me), obtained in 60% yields by method (b), crystallised from methyl alcohol in colourless needles, m. p. 125—126° (Found : C, 73·7; H, 5·0. $C_{18}H_{15}O_3N$ requires C, 73·7; H, 5·2%). This imide, which is soluble in sodium hydroxide solution, was refluxed for 1 hour with methyl-alcoholic hydrogen chloride and converted quantitatively into methyl phenylacetate and 2-methylhomophthalimide. The phenylacetyl derivative was refluxed for 12 hours with excess of methyl iodide in methyl alcohol containing potassium hydroxide (1·1 mols.). The methyl alcohol and the excess of methyl iodide were removed, the residue diluted with water, and the alkali-insoluble *4-phenylacetyl-2 : 4-dimethylhomophthalimide* collected and crystallised from methyl alcohol; it separated in long rectangular prisms, m. p. 127—128° (Found : C, 74·4; H, 5·3. $C_{19}H_{17}O_3N$ requires C, 74·3; H, 5·5%). Hydrolysis with methyl-alcoholic hydrogen chloride yielded methyl phenylacetate and 2 : 4-dimethylhomophthalimide, which separated from dilute methyl alcohol in colourless needles, m. p. 64—65°. Gabriel and Posner (*Ber.*, 1894, **27**, 2496) give m. p. 64—66°.

4-(3′ : 4′-Dimethoxyphenyl)acetyl-2-methylhomophthalimide [I; R = $C_6H_3(OMe)_2{\cdot}CH_2$, X = Me], obtained in 60% yields by method (b), separated from methyl alcohol in colourless needles, m. p. 133—134° (Found : C, 67·8; H, 5·3. $C_{20}H_{19}O_5N$ requires C, 67·7; H, 5·4%). Unsuccessful

attempts were made to cyclise this imide with 80% sulphuric acid, phosphoric oxide in toluene and xylene, phosphorus oxychloride and pentachloride in chloroform.

4-(3′ : 4′-*Methylenedioxyphenyl)acetyl-2-methylhomophthalimide* (I; R = $CH_2{:}O_2{:}C_6H_3{\cdot}CH_2$, X = Me), obtained in 65% yields, separated from methyl alcohol in colourless needles, m. p. 141—142° (Found : C, 67·4; H, 4·6. $C_{19}H_{15}O_5N$ requires C, 67·6; H, 4·5%).

4 : 4-*Diphenacyl-2-methylhomophthalimide.*—2-Methylhomophthalimide (2 g.) was dissolved in methyl alcohol (20 c.c.) containing sodium methoxide, prepared from sodium (0·4 g.), and ω-bromoacetophenone (3 g.) was added to the cold solution. Heat was evolved and a solid rapidly separated. After the mixture had been warmed on the water-bath for ½ hour, water was added; the solid obtained (3·5 g.) crystallised from glacial acetic acid in colourless prisms, m. p. 247—248° [Found : C, 75·7; H, 5·4; *M* (Rast), 402. $C_{26}H_{21}O_4N$ requires C, 75·9; H, 5·4%; *M*, 411]. The yield was increased to 5 g. by employing ω-bromoacetophenone (5 g.) in the experiment.

4-*Benzoylhomophthalimide* (I; R = C_6H_5, X = H), obtained in 70% yields by method (b), crystallised from glacial acetic acid in colourless needles, m. p. 280° (Found : C, 72·4; H, 4·3. $C_{16}H_{11}O_3N$ requires C, 72·5; H, 4·2%). This imide was boiled for 6 hours with 10% sodium hydroxide solution (5 parts); ammonia was evolved and acidification of the solution yielded *o*-carboxybenzyl phenyl ketone (II), which separated from aqueous alcohol in slender needles, m. p. 163—164°. Graebe and Trumpy (*Ber.*, 1898, **31**, 377) give m. p. 162—163° (Found : equiv., 238. Calc. for $C_{15}H_{12}O_3$, equiv., 240).

4-*Phenylacetylhomophthalimide* (I; R = $C_6H_5{\cdot}CH_2$, X = H), obtained in 65% yields, crystallised from acetic acid in colourless needles, m. p. 274—275° (Found : C, 73·1; H, 5·0. $C_{17}H_{13}O_3N$ requires C, 73·1; H, 4·7%).

4-(3′ : 4′-*Dimethoxyphenyl)acetylhomophthalimide* [I; R = $C_6H_3(OMe)_2{\cdot}CH_2$, X = H], obtained in 60% yields, separated from acetic acid in colourless needles, m. p. 282—283° (Found : C, 67·5; H, 5·1. $C_{19}H_{17}O_5N$ requires C, 67·3; H, 5·1%).

Condensation of 2-Methylhomophthalimide with O-Methyleugenol Oxide.—This experiment was carried out by Mr. W. Kelly, B.Sc. A solution of 2-methylhomophthalimide (2 g.) and *O*-methyleugenol oxide (2 g.) in methyl alcohol (10 c.c.) containing sodium methoxide (from sodium, 0·28 g.) was allowed to react at room temperature for 7 days. Water was added and neutral substances were removed in ether. The alkaline layer was acidified and extracted with ether. The extract was dried, and the solvent removed; the *product* (IV) crystallised from methyl alcohol in colourless rectangular prisms (1·0 g.), m. p. 135—136° (Found : C, 68·4; H, 6·2. $C_{21}H_{23}O_5N$ requires C, 68·3; H, 6·2%). After standing overnight in the cold with 80% sulphuric acid, the compound (IV) was converted into homophthalic acid.

Action of Potassium Cyanide on 6 : 7-*Dimethoxy-3-phenacylphthalide.*—Potassium cyanide (2·2 g.) in water (10 c.c.) was added to a solution of 6 : 7-dimethoxy-3-phenacylphthalide (5 g., prepared from opianic acid and acetophenone as described by Goldschmidt, *loc. cit.*) in 3·5% sodium hydroxide solution (15 c.c.). Glacial acetic acid (1 c.c.) was added to the cold solution and after 24 hours the brown solution was acidified and the supernatant liquid decanted from the brown oil. The latter was warmed on the water-bath for 1 hour with concentrated hydrochloric acid (25 c.c.), the yellow solid was collected, washed first with water and then with methyl alcohol, and crystallised from glacial acetic acid or better from nitrobenzene; the *compound* (V) separated in bright yellow needles (6·2 g.), m. p. 282° (Found : C, 71·2; H, 4·9; N, 4·4. $C_{19}H_{15}O_4N$ requires C, 71·0; H, 4·7; N, 4·4%). This compound (V) (2 g.) was boiled with 10% sodium hydroxide solution (40 c.c.); ammonia was rapidly evolved and after ½ hour the solution was filtered from traces of insoluble material and acidified. The white precipitate obtained crystallised from methyl alcohol in colourless prisms (1·5 g.), m. p. 184—185° (decomp.) (Found : C, 61·3; H, 5·0%), which have not been identified.

6 : 7-*Dimethoxy-3-(3′ : 4′-dimethoxy)phenacylphthalide.*—Methyl alcohol was added to a suspension of acetoveratrone (10 g.) and opianic acid (12 g.) in 10% sodium hydroxide solution (36 c.c.) until a homogeneous solution was obtained. After 24 hours, the mixture was acidified with hydrochloric acid and warmed for a few minutes; the product crystallised from methyl alcohol or acetic acid in colourless needles (14 g.), m. p. 165—167° (Found : C, 64·3; H, 5·5. $C_{20}H_{20}O_7$ requires C, 64·5; H, 5·4%).

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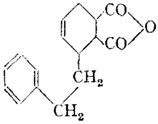
267. *The Synthesis of Compounds related to the Sterols, Bile Acids, and Oestrus-producing Hormones. Part XI. A "Diene-Synthesis" of Phenanthrene and Hydrophenanthrene Derivatives.*

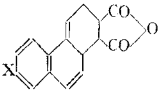
By A. COHEN and (in part) F. L. WARREN.

THE failure to cyclise 3-β-phenylethyl-1 : 2 : 3 : 6-tetrahydrophthalic anhydride (I) (Cohen, J., 1935, 429) presented a serious obstacle to the synthesis of *as.*-octahydrophenanthrene derivatives by the Diels reaction. Alternative routes were therefore investigated involving the condensation of maleic anhydride with derivatives of naphthalene and 3 : 4-dihydronaphthalene containing a 1-vinyl group; the conjugation of an aromatic nucleus with an ethylenic linkage to give an active diene system had been observed in the case of *as.*-diphenylethylene (Wagner-Jauregg, *Annalen*, 1931, **491**, 1).

Ethyl 3 : 4-dihydro-1-naphthylacetate was prepared through the Reformatsky reaction between α-tetralone and ethyl bromoacetate (Schroeter, Zadek, and Hoffmann, *Ber.*, 1925, **58**, 713), but this could not be reduced to the required β-(3 : 4-dihydro-1-naphthyl)ethyl alcohol by the Bouveault–Blanc method, the only product being the saturated β-1-tetrahydronaphthylethyl alcohol. This result was anticipated in view of the known facility with which a double bond conjugated with a benzene nucleus is reduced by sodium and alcohol, and is in agreement with the subsequently recorded finding of Robinson and Walker (J., 1935, 1530).

1-Vinylnaphthalene, however, combines readily with maleic anhydride, affording 1 : 2 : 3 : 11-*tetrahydrophenanthrene*-1 : 2-*dicarboxylic anhydride* (II; X = H), and the present communication describes experiments of this nature which were mostly completed by April, 1936, when circumstances caused the work to be interrupted. A preliminary note on some of these experiments has already been published (*Nature*, 1935, **136**, 869).

(I.) 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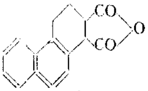
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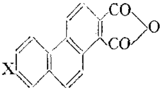
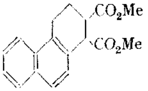
(IV.) 

 (V.)

Formula (II) is that of the theoretical primary addition product from 1-vinylnaphthalene and maleic anhydride, and it was realised that such a molecule could easily isomerise to a naphthalene derivative (III) which might well represent the product actually obtained. Experimental evidence, however, demonstrated the correctness of (II). The adduct is found by fractional dissolution to be homogeneous; it rapidly consumes cold alkaline permanganate, and perbenzoic acid titration gives a value of 1·7 for the number of ethylenic linkings, the alternatives being 2 for (II) and 0 for (III). Moreover, (II) is readily isomerised by hydrogen chloride to a *compound* which must be represented by (III). The latter has the same chemical composition, is far more stable to alkaline permanganate, and is much more soluble in benzene. Its saturated character is shown by the negligible absorption of oxygen from perbenzoic acid.

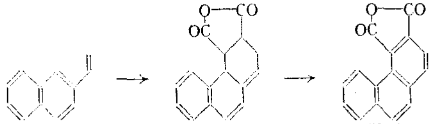
The ease of isomerisation of (II) to (III) was shown by treatment of the former with cold alkaline methyl sulphate, which, without introducing any acid factor, gave the same *methyl* ester (V) as was obtained in the methyl alcohol–sulphuric acid esterification of the free acid obtained from (III).

Finally, the close relationship between (II) and (III) was demonstrated by dehydrogenating both with platinum-black at 300° to the same phenanthrene-1 : 2-dicarboxylic

anhydride (IV; X = H), which had just previously been described by Fieser and Hershberg (*J. Amer. Chem. Soc.*, 1935, **57**, 1508, 1853).

In a parallel series of experiments β-1-(6-methoxynaphthyl)ethyl alcohol was dehydrated to 6-*methoxy*-1-*vinylnaphthalene*, which also reacts with maleic anhydride. To the *adduct*, of which only a very small quantity has been available, the structure (II; X = OMe) is assigned by analogy with the results in the case where X = H. Its reduction of permanganate has been observed, and on dehydrogenation, it is converted into 7-methoxyphenanthrene-1 : 2-dicarboxylic anhydride, identical with a specimen synthesised by another route (Part IX; J., 1936, 52).

As a third example of this type of Diels reaction, 2-vinylnaphthalene (VI) reacts with maleic anhydride, though much less readily, furnishing 2 : 3 : 4 : 12-*tetrahydrophenanthrene*-3 : 4-*dicarboxylic anhydride* (VII). The assumed location of the double bonds in (VII) is


(VI.) (VII.) (VIII.)

once more based on analogy. The phenanthrene type of structure is, however, definitely established, and the anthracene type (which would result from condensation of maleic anhydride in the only alternative manner) excluded by the identity of the dehydrogenation *product* (VIII) obtained from (VII) with a specimen independently synthesised by Dr. C. L. Hewett, to whom the author is grateful.

The anhydride (II; X = H) in dioxan solution was submitted to catalytic hydrogenation with palladium-black, with a view to converting it into an octahydrophenanthrene derivative more closely resembling an oestrone type of compound. Nearly half of the calculated volume of hydrogen was absorbed, resulting in an obviously mixed product of a gummy nature. The only homogeneous product isolated did not depress the melting point of the isomer (III). This migration of the ethylenic linking by means of the catalyst recalls the isomerisation of β- to α-pinene (Richter and Wolff, *Ber.*, 1926, **59**, 1733) effected by platinum and palladium, and of γ- to α-ergostenol (Reindel and Walter, *Annalen*, 1928, **460**, 214; v. Reichel, *Z. physiol. Chem.*, 1934, **226**, 146). Hydrogenation in alkaline solution failed, as was to be expected from the ease with which (II) passes into (III) in alkaline medium.

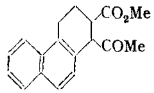
Further experiments, aimed at the building up of a five-carbon ring in place of the anhydride ring, were confined to the naphthalenic isomer (III) in order to avoid the complications associated with the labile compound (II; X = H). Bouveault–Blanc reduction did not yield a hydroxy-acid or lactone, and only the dibasic acid corresponding to unchanged material was obtained.

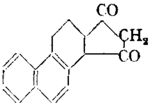
The reaction between the anhydride (III) and one molecular equivalent of methylmagnesium iodide afforded a mixture of compounds. This was resolved after esterification treatment with methyl alcohol and sulphuric acid into (*a*) the characteristic crystalline *dimethyl-lactone* (XI; in this formula CMe_2 and CO are interchangeable, as the exact orientation has not been determined) arising from reaction between initially formed ketone (IX) with more Grignard reagent, followed by lactonisation of the resulting tertiary

(IX.) (X.) (XI.)

carbinol-acid corresponding to (X); (*b*) the methyl ester (V) of the original dibasic acid; and (*c*) a compound, b. p. 185—190°/0·2 mm., obtained in very small yield, which is

probably the desired keto-ester (XII). The last yields an acid on alkaline hydrolysis, but further investigation was prevented by the small quantity available. It was hoped to

(XII.) 

 (XIII.)

cyclise this keto-ester to 1′ : 3′-diketo-3 : 4-dihydro*cyclo*pentanophenanthrene (XIII). An attempt to obtain this diketone by the alternative method of condensing the methyl ester (V) with ethyl acetate, followed by hydrolysis and decarboxylation, led to a small yield of a crystalline product, but dehydrogenation had occurred at some stage, as the analytical figures and properties were in very good agreement with the phenanthrene analogue of (XIII), which has been described by Fieser and Hershberg (*J. Amer. Chem. Soc.*, 1936, **58**, 2322).

Note on Biological Testing [By F. L. Warren].

Lactonic degradation products of oestriol methyl ether, of somewhat analogous structure to some of the synthetic compounds now described, were reported by MacCorquodale, Levin, Thayer, and Doisy (*J. Biol. Chem.*, 1933, **101**, 753) to have a higher oestrogenic activity than oestrone, and Fieser and Hershberg (*J. Amer. Chem. Soc.*, 1935, **57**, 1852) claimed a moderately high order of oestrogenic activity for the anhydride of phenanthrene-1 : 2-dicarboxylic acid and its 3 : 4-dihydro-derivative. Hence tests for oestrogenic activity have been carried out with many of the compounds described in this and a previous communication (Cohen, Cook, and Hewett, J., 1936, 52). The technique used was the ordinary Allen and Doisy procedure of examining vaginal smears after injection of the substances into ovariectomised mice. The compounds were mostly very sparingly soluble, and in the higher doses were injected in suspension in sesame oil. Contrary to expectation, no oestrogenic activity whatever was shown by any of the compounds in the doses in which they were administered. Five mice were normally used for each test, and the doses were spaced so that six injections were given during 48 hours; smears were examined up to 96 hours after the last injection. The compounds tested, with the total amount administered to each mouse, were as follows :

Compound.	Doses, mg.
Phenanthrene-1 : 2-dicarboxylic anhydride	0·1, 0·5, 5·0
1 : 2 : 3 : 4-Tetrahydrophenanthrene-1 : 2-dicarboxylic anhydride	5·0
1 : 2 : 3 : 11-Tetrahydrophenanthrene-1 : 2-dicarboxylic anhydride	0·1, 0·5, 5·0
7-Methoxyphenanthrene-1 : 2-dicarboxylic anhydride	0·5, 5·0
7-Methoxy-3 : 4-dihydrophenanthrene-1 : 2-dicarboxylic anhydride	0·1, 0·5, 5·0
7-Hydroxy-3 : 4-dihydrophenanthrene-1 : 2-dicarboxylic anhydride	0·1, 0·5
Dimethyl-lactone (XI) from 1 : 2 : 3 : 4-tetrahydrophenanthrene-1 : 2-dicarboxylic anhydride and methylmagnesium iodide	10

On account of the low solubility of these anhydrides in sesame oil absorption by the animals must be very slow, and additional tests were made by injecting aqueous solutions of sodium 7-methoxy-3 : 4-dihydrophenanthrene-1 : 2-dicarboxylate in both mice and rats, so that each mouse received 10 mg. of material, and each of 4 rats received 100 mg. There was no sign of oestrus in any animal.

From these results it is evident that none of the compounds examined has any oestrogenic activity when examined in accordance with the standard procedure. It subsequently transpired that the activity originally claimed for phenanthrene-1 : 2-dicarboxylic anhydride and its 3 : 4-dihydro-compound (Fieser and Hershberg, *loc. cit.*) was estimated by a new method of assay (Pincus and Werthessen, *Science*, 1936, **84**, 45) and it was afterwards admitted by Fieser and Hershberg (*J. Amer. Chem. Soc.*, 1936, **58**, 2315) that their earlier statement was misleading and that the anhydrides gave negative results when tested by the standard technique. Also MacCorquodale, Levin, and Thayer (*J. Biol Chem.*, 1934, **105**, lv) appear to have withdrawn their earlier claim (*loc. cit.*), for in a note on the degradation products of oestriol methyl ether they state " none of the derivatives of

theelin and theelol so far obtained has any significant oestrogenic activity." * Thus there is now general agreement that compounds of the type under review in the present communication have no oestrogenic activity of any practical importance [The Research Institute, The Royal Cancer Hospital (Free)].

EXPERIMENTAL.

1-*Vinylnaphthalene* (cf. Sontag, *Ann. Chim.*, 1934, 1, 359).—1-β-Naphthylethyl alcohol (24 g.) was added dropwise to solid potassium hydroxide in pellet form (16 g.), maintained at 165°/15 mm. in a Claisen flask fitted with a cooled receiver, in which a wet distillate accumulated. This was dissolved in ether, dried with calcium chloride, and freed from solvent. The product, a colourless refractive liquid (17·6 g.), was used directly for condensation with maleic anhydride.

1 : 2 : 3 : 11-*Tetrahydrophenanthrene*-1 : 2-*dicarboxylic Anhydride* (II; X = H).—A solution of 1-vinylnaphthalene (7·5 g.) and maleic anhydride (5 g.) in xylene (15 c.c.) was heated on the water-bath for 20 minutes and allowed to cool; it set to a crystalline mass, which was washed with benzene after 3 days. The *adduct* (4 g.) crystallised from glacial acetic acid, acetic anhydride, or, better, dioxan, in fine needles, sintering at 176°, m. p. 186—189° (Found: C, 75·9; H, 5·0. $C_{16}H_{12}O_3$ requires C, 76·15; H, 4·8%). It was insoluble in cold dilute sodium hydroxide solution, dissolved on warming, and the chilled solution reduced permanganate instantly. Perbenzoic acid titration corresponded to a consumption of 1·7 atoms of oxygen per molecule, against the required value of 2.

1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-1 : 2-*dicarboxylic Anhydride* (III).—When the above adduct (10 g.) was boiled for 45 minutes with glacial acetic acid saturated with hydrogen chloride (100 c.c.), it passed readily into solution and, on cooling, the isomeric *anhydride* crystallised (8·5 g.). The latter was much more soluble in hot glacial acetic acid and crystallised from it in compact colourless prisms, m. p. 167—168° (Found: C, 76·0; H, 4·8. $C_{16}H_{12}O_3$ requires C, 76·15; H, 4·8%). It gradually became yellow when crystallised from benzene or sublimed in a vacuum. Brief heating in alkaline solution, followed by acidification, yielded 1 : 2 : 3 : 4-*tetrahydrophenanthrene*-1 : 2-*dicarboxylic acid*, which crystallised from glacial acetic acid in minute rhombs, m. p. 220° (decomp.) (Found: C, 71·0; H, 5·3. $C_{16}H_{14}O_4$ requires C, 71·05; H, 5·2%).

Homogeneity of the Adduct (II; X = H).—The crystallised adduct (1 g.), m. p. 186—189°, was finely powdered and refluxed with pure benzene (20 c.c.) for 1 hour. Most of it remained undissolved and was unchanged. The solution was evaporated to dryness, yielding 0·15 g. of crystalline material, which was slightly less pure adduct, m. p. 180—185°, and gave no depression in m. p. with the original. There was no evidence of the presence of the naphthalene isomer which is much more soluble in benzene (not less than 0·5 g. in 20 c.c.).

Methyl 1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-1 : 2-*dicarboxylate* (V).—(*a*) The recrystallised adduct (1 g.) was dissolved in warm dilute sodium hydroxide solution, cooled, and treated with methyl sulphate (2 g.) at room temperature, the mixture being constantly shaken and kept alkaline. After an hour the insoluble material was extracted with ether, from which 0·2 g. of the *ester* was isolated; this crystallised from methyl alcohol in stout rhombic prisms, m. p. 105—106° (Found: C, 72·2; H, 6·0. $C_{18}H_{18}O_4$ requires C, 72·5; H, 6·1%), not depressed by the product from (*b*).

(*b*) The naphthalenic isomer (III) (5 g.) was esterified in the usual way with 50 c.c. of methyl alcohol which was saturated with dry hydrogen chloride, or treated with concentrated sulphuric acid (5 c.c.). The product (4 g.) was identical with that from (*a*).

Condensation of Methyl 1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-1 : 2-*dicarboxylate with Ethyl Acetate*.—To a solution of the methyl ester (V) (3·3 g.) in ethyl acetate (40 c.c.) were added 1·5 g. of fine sodium wire, which readily dissolved under reflux. More sodium wire was added (2 g.), and the mixture refluxed overnight and cooled for a day. The solid which separated was collected after addition of anhydrous ether (100 c.c.). It was heated at 100° for 1 hour with 5N-hydrochloric acid (20 c.c.). Vigorous evolution of carbon dioxide ensued. The cooled product (0·2 g.) crystallised from benzene or acetone in fine, pale yellow needles, m. p. 240° (corr.) in a Pyrex tube, and decomposing above 240° in soft glass; this compound gives no colour with ferric chloride, absorbs bromine readily, and gives a red alkaline solution, and is no doubt identical with 1′ : 3′-diketo*cyclo*pentenophenanthrene, which has been described by Fieser and Hershberg (*loc. cit.*) [Found (micro.): C, 82·8; H, 3·9. Calc.: C, 82·9; H, 4·1%].

* Thayer, MacCorquodale, and Doisy (*J. Pharm. Exp. Ther.*, 1937, 59, 52) now explain that faulty technique was responsible for their original claim that these compounds were highly active.

The Action of Methylmagnesium Iodide on 1 : 2 : 3 : 4-*Tetrahydrophenanthrene*-1 : 2-*dicarboxylic Anhydride*.—A solution of the anhydride (III) (5 g.) in sodium-dried benzene (50 c.c.) was chilled in a freezing mixture and to the fine suspension was slowly added with shaking the Grignard reagent prepared from methyl iodide (3 g.), magnesium (0·5 g.), and anhydrous ether (20 c.c.). The mixture was allowed to reach room temperature, warmed at 50° for 1 hour, and after standing at room temperature for 1 hour was decomposed with ice and dilute sulphuric acid. The insoluble product was collected and added to the resinous residue from the benzene-ether solution in the filtrate. The total product so obtained was dried in a vacuum over sulphuric acid, and refluxed for 3 hours in methyl alcohol (50 c.c.) containing concentrated sulphuric acid (5 c.c.). The solvent was removed under reduced pressure, and the residue treated with water and extracted with ether. The ethereal solution was washed with cold sodium carbonate solution, which, on acidification, gave a small amount of acid methyl ester as shown by titration and by the fact that further esterification yielded the dimethyl ester (V). The washed and dried ethereal solution was evaporated till a white solid separated. This was filtered off (0·8 g.) from the chilled solution, and crystallised from glacial acetic acid, affording the *dimethyl-lactone* (XI) in colourless flat needles, m. p. 213·5—214·5° [Found (micro.): C, 81·0; H, 6·8. $C_{18}H_{18}O_2$ requires C, 81·15; H, 6·8%]. When this was heated with alcoholic potash, the water-soluble potassium salt of the corresponding hydroxy-acid was obtained; and acidification regenerated the lactone.

When the ethereal mother-liquor was allowed to evaporate slowly, the methyl ester (V) was obtained (1·5 g. of recrystallised material). The final ethereal mother-liquor yielded a gum, which was distilled, giving 0·5 g. of a viscous yellow oil, b. p. 185—190°/0·2 mm., insoluble in alkali but soluble on heating. Acidification yielded an acidic product. A small quantity of this oil appeared to react readily with sodium in toluene solution, but a satisfactory product such as might be expected from the keto-ester (XII) could not be isolated.

Hydrogenation of the Adduct (II; X = H).—(*a*) A dioxan solution (50 c.c.) of the adduct (1·26 g.) was shaken at 45—50° with palladium-black (0·5 g.) in an atmosphere of hydrogen, under a pressure of 70 cm. of water. After 150—175 c.c. of hydrogen had been absorbed (calc. for two double bonds, *ca.* 250 c.c.) in 5 hours, reaction appeared to have ceased. The filtered solution gave, on evaporation under reduced pressure, a brownish gum, which partly solidified on rubbing with glacial acetic acid–*cyclo*hexane; yield, 0·75 g. This crystallised from glacial acetic acid in prisms, m. p. 166—168°, not depressed by the anhydride (III).

(*b*) The adduct (2·7 g.) was dissolved in warm 0·5*N*-sodium hydroxide (50 c.c.) and after the addition of palladium-black (0·5 g.) was shaken with hydrogen as in (*a*) but at room temperature. After a rapid initial absorption of hydrogen (90 c.c.), readily accounted for by the catalyst, absorption was slow and ceased after 1 hour. On acidification of the filtered solution, the dicarboxylic acid was obtained, which was converted into its anhydride, identified as (III).

6-*Methoxy*-1-*vinylnaphthalene*.—This was prepared in exactly the same manner as 1-vinylnaphthalene from β-1-(6-methoxynaphthyl)ethyl alcohol (Cohen, Cook, and Hewett, J., 1934, 657; 1935, 451) (8·5 g.) and potassium hydroxide (5 g.) at 160—170°/1 mm. The crude dry product crystallised spontaneously (4·1 g.) and separated from methyl alcohol in colourless leaflets, m. p. 41—42° (Found: C, 84·6; H, 6·4. $C_{13}H_{12}O$ requires C, 84·7; H, 6·6%), being readily obtained pure by regeneration from its *picrate*. This, prepared in the usual way in alcoholic solution, separated from alcohol in orange needles, m. p. 114·5° [Found (micro.): C, 54·7; H, 3·7. $C_{19}H_{15}O_8N_3$ requires C, 55·2; H, 3·7%].

7-*Methoxy*-1 : 2 : 3 : 11-*tetrahydrophenanthrene*-1 : 2-*dicarboxylic Anhydride* (II; X = OMe).—A solution of 6-methoxy-1-vinylnaphthalene (2·8 g.) and maleic anhydride (1·4 g.) in xylene (6 c.c.) was warmed on the water-bath for 15 minutes and left at room temperature for 4 days. The solid which separated was collected, washed with benzene, and digested with cold water to remove maleic anhydride; yield, 1·3 g. It crystallised from acetonitrile in small colourless rods, m. p. 171—175° (softening at 165°) to an opaque melt which decomposed with effervescence [Found (micro.): C, 72·2; H, 5·2. $C_{17}H_{14}O_4$ requires C, 72·3; H, 5·0%]. An alkaline solution instantly reduced permanganate.

Dehydrogenation. The above adduct (50 mg.) was heated with platinum-black (50 mg.) at 280° for 30 minutes. The temperature was raised to 300°, and the product sublimed (40 mg.) at the pressure of the water-pump. Crystallisation from glacial acetic acid yielded 7-methoxyphenanthrene-1 : 2-dicarboxylic anhydride (IV; X = OMe) in fine yellow needles, m. p. 252—254°, not depressed by a synthetic specimen (Cohen, Cook, and Hewett, J., 1936, 52).

2 : 3 : 4 : 12-*Tetrahydrophenanthrene*-3 : 4-*dicarboxylic Anhydride* (VII).—β-2-Naphthylethyl

alcohol (10 g.) was dehydrated with potassium hydroxide (7 g.) at 170°/14 mm. The crude dried product, 2-vinylnaphthalene (3·1 g.), was worked up as described above, and treated with maleic anhydride (2 g.) in xylene (10 c.c.) for 10 minutes on the water-bath. After 7 days at room temperature, the solid which had separated was collected (0·3 g.). The product crystallised from glacial acetic acid in prismatic needles of indefinite m. p. 170—180°, decomposing above 190° [Found (micro.): C, 75·8; H, 4·8. $C_{16}H_{12}O_3$ requires C, 76·15; H, 4·8%].

Dehydrogenation. This adduct (90 mg.) and platinum-black (50 mg.) were heated at 300° for 1 hour. The sublimed product, obtained as above, crystallised from glacial acetic acid in pale yellow needles, m. p. 243—244°, which was not depressed by an authentic specimen, m. p. 246—247°, prepared by Dr. C. L. Hewett by platinum dehydrogenation of 1 : 2-dihydrophenanthrene-3 : 4-dicarboxylic anhydride (Fieser and Hershberg, *J. Amer. Chem. Soc.*, **1935**, **57**, 1853; cf. Fieser, Fieser, and Hershberg, *ibid.*, 1936, **58**, 2323).

The author is indebted to the Medical Research Council for a grant, to Prof. J. W. Cook for his encouraging interest in the investigation, and to the Directors of Messrs. Boots Pure Drug Co., Ltd., for facilities to complete experiments.

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268. *Sugar Osazones and their Anhydrides.*

By E. E. PERCIVAL and E. G. V. PERCIVAL.

This paper deals with further investigations on the production of anhydro-osazones by the deacetylation of osazone acetates. A monoanhydro-lactosazone and two isomeric monoanhydro-maltosazones are described, all of which yield penta-acetates and therefore possess a pyranose ring structure in addition to the pyrazolidine or pyridazine ring. The monoanhydro-glucosazone and -galactosazone described by Diels and his co-workers also appear to contain an oxide ring, since they yield diacetates on acetylation.

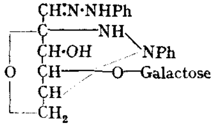
It is pointed out as a result of further work on the differential deacetylation of osazone acetates that this titration method cannot be used as evidence of the cyclic structure or otherwise of such derivatives.

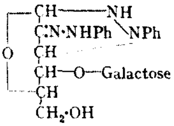
IT was shown by one of us (J., 1936, 1770) that the deacetylation of the acetyl derivatives of glucosephenylosazone and galactosephenylosazone gave rise to the same dianhydro-hexosazone, for which a structure was proposed incorporating a pyrazoline, a pyrazolidine, and a pyranose ring. Previously Diels and Meyer (*Annalen*, 1935, **519**, 157) and later Diels, Meyer, and Onnen (*ibid.*, 1936, **525**, 94) had reported the isolation of monoanhydro-glucosazone, -galactosazone, -lactosazone, -xylosazone, -arabinosazone, -cellobiosazone, dianhydro-maltosazone and other similar derivatives by the action of sulphuric acid in alcoholic solution on the osazones. Emil Fischer in his classical paper on osazone formation (*Ber.*, 1887, **20**, 830) had also reported the isolation of anhydrolactosazone by this method.

We have now investigated further the possibility of anhydride formation in the sugar osazone series by the deacetylation method for the acetates of the phenylosazones of lactose, maltose, *d*-xylose, *l*-arabinose, and *l*-rhamnose, as well as for certain phenylhydrazones and methylphenylhydrazones, but positive results have been obtained only in the case of the first two substances.

Lactosazone yields an amorphous ***hepta-acetate***, which on deacetylation reverts to the same anhydro-derivative (m. p. 232°) as that described by Fischer and by Diels and Meyer (*locc. cit.*). Ultimate analysis reveals the fact that the formula must be represented as $C_{24}H_{32}O_9N_4$, and since it is not identical with lactosazone it appears to be a hydrated anhydride. The corresponding acetyl derivative crystallises with one molecule of benzene and appears to be a ***penta-acetyl monoanhydrolactosazone***, the analytical figures not being in agreement with those required by a dianhydrolactosazone tetra- or penta-acetate, or by monoanhydrolactosazone hexa-acetate. It is probable, therefore, that a pyranose ring

structure is present in this monoanhydrolactosazone and it can accordingly be formulated as either (I) or (II).

(I.) 

 (II.)

It should be noted that the above formulæ are not stereochemical.

Crystalline *maltosazone hepta-acetate* gave two distinct products on deacetylation: (A) $C_{24}H_{30}O_8N_4$, long, lemon-yellow needles, m. p. 245°, $[\alpha]_D^{20°}$ + 57·6° in pyridine (*c*, 0·38), and (B) $C_{24}H_{34}O_{10}N_4$, pointed, yellow plates, m. p. 194°, $[\alpha]_D^{20°}$ + 160° in pyridine (*c*, 0·23). Since by no method of dehydration or hydration attempted was it possible to interconvert (A) and (B), coupled with the evidence of the specific rotations, it is necessary to conclude that the two derivatives are structurally different. The possibility too that (B) is maltosazone hydrate can be ruled out on the basis of the rotational evidence and the fact that on acetylation (B) yields a *penta-acetate*, $C_{34}H_{40}O_{13}N_4$, and not maltosazone hepta-acetate. Acetylation of (A) also yields an amorphous *penta-acetate* of the same composition but with properties markedly different from those of acetylated (B). The simplest explanation available is that (A) and (B) are the isomeric ring forms corresponding to formulæ (I) and (II) suggested for the anhydrolactosazone, but it has not yet been found possible to distinguish between the two forms. It is interesting to note that, although by the deacetylation method glucosazone yields a dianhydrohexosazone and maltosazone and lactosazone monoanhydrides, yet Diels and Meyer (*loc. cit.*) by their method obtained a monoanhydroglucosazone and a dianhydromaltosazone.

In a paper (J., 1935, 1398) a structure for glucosazone was proposed embodying a fructopyranose ring on the basis of methylation experiments. There seems to be no reason why this should not hold for the anhydro-osazones of the disaccharides now considered, but since no experimental proof is yet available for these derivatives it is necessary to suspend judgment on the location of the oxide ring which is undoubtedly present.

The *triacetates* of *d*-xylosazone, *l*-arabinosazone and *l*-rhamnosazone were prepared, but despite repeated attempts crystalline anhydro-osazones could not be obtained by the deacetylation method, although Diels, Meyer, and Onnen (*loc. cit.*) found it possible with acidified alcohol to prepare monoanhydrides of xylosazone and arabinosazone.

Since all the osazone anhydrides prepared by deacetylation appeared to possess an oxide ring structure, it seemed of interest to investigate whether the monoanhydrides of Diels were of the same type. Accordingly his monoanhydro-glucosazone and -galactosazone were prepared and acetylated. The former yielded an amorphous *diacetate*, $[\alpha]_D^{17°}$ − 125°, and a crystalline *diacetyl monoanhydrogalactosazone*, $[\alpha]_D^{17°}$ + 64°, was also isolated. These results would suggest that these monoanhydrides possess an oxide ring structure. This is supported by the observation of Diels, Meyer, and Onnen (*loc. cit.*) that they yield dibenzoates, but these authors also report the isolation of triacetates. The latter observation may be due to acetylation on one of the nitrogen atoms of the hydrazone residue due to the employment of vigorous methods of acetylation. No specific rotations were recorded for these derivatives.

Fructosemethylphenylosazone tetra-acetate on deacetylation yielded the original osazone as would be expected, since no α-hydrogen atom is available for anhydride formation; Diels and Meyer (*loc. cit.*) record a similar observation for their acid alcohol method. Incidental to the preparation of fructosemethylphenylosazone a compound which appears to be a *fructosemethylphenylhydrazone*, m. p. 170°, $[\alpha]_D^{17°}$ − 253°, yielding a *penta-acetate*, m. p. 121°, $[\alpha]_D^{17°}$ + 86·5°, was isolated. Ofner (*Monatsh.*, 1905, **26**, 1165) has described a fructosemethylphenylhydrazone of m. p. 116—120°. It was not found possible to isolate an anhydro-compound from the acetate of glucosephenylhydrazone or from *glucosemethylphenylhydrazone penta-acetate*.

Because of the importance of being able to distinguish between *O*-acetyl and *N*-acetyl groups in this work and because the results in a previous paper (Percival, *loc. cit.*) did not agree with those of Wolfrom, Konigsberg, and Soltzberg (*J. Amer. Chem. Soc.*, 1936, **58**, 490) an extensive survey of the method previously described has been carried out. Repetition of the work on tetra-acetyl galactosazone and tetra-acetyl glucosazone with the conditions of temperature prescribed by Kunz and Hudson (*J. Amer. Chem. Soc.*, 1926, **48**, 1982) indicated the presence of *ca.* 30—31% of *O*-acetyl group, and we are now in complete agreement with Wolfrom and his co-workers on the experimental facts. The reason for the discrepancy was the inaccuracy below 0° of the thermometer used for registering the temperature of the freezing mixture, with the result that the earlier experiments had been conducted at − 15° to − 18° instead of *ca.* − 5°. Whereas at the lower temperature results were obtained, and these are now confirmed, corresponding to the removal of but three acetyl residues, it is apparent that the speed of deacetylation under these conditions will be much reduced, and experiments with octa-acetyl lactose reveal that, although 20 minutes at room temperature is sufficient to eliminate all the acetyl residues, at − 20° only about 90% is removed in 2 hours, so that the agreement may be fortuitous. It must be emphasised, however, that it does not follow that the compounds in question do not contain *N*-acetyl groups, and are therefore acyclic. It is clear that it is not sufficient to compare *O*-acetylated compounds with such derivatives as acetanilide and methylacetanilide, which are untouched during 24 hours with *N*/10-sodium hydroxide at room temperature, since the compounds under review, if cyclic, will be acetylated hydrazides. Accordingly the ease of deacetylation of α-acetylphenylhydrazine, β-acetylphenylhydrazine, αβ-diacetylphenylhydrazine and benzaldehyde-α-acetylphenylhydrazone was studied. The general conclusion emerges that such compounds are hydrolysed much more easily than *N*-acetylated amines, but to a varying extent; *e.g.*, β-acetylphenylhydrazine requires but 2 hours at room temperature under the prescribed conditions to lose 50% of its acetyl residues and diacetylphenylhydrazine loses almost the same proportion in 10 minutes, although benzaldehyde-α-acetylphenylhydrazone only loses 13% and α-acetylphenylhydrazine 7% in 2 hours. It is therefore clear that a sharp differentiation between NH·NAc and OAc is difficult by the method proposed and that the question of the structure of the osazone acetates cannot yet be regarded as settled.

Experimental.

Acetylation of Lactosephenylosazone.—The method described for the acetylation of dianhydrohexosazone (J., 1936, 1773) was employed, giving, in almost quantitative yield, an amorphous yellow powder, which was washed, dried, dissolved in benzene, and precipitated with light petroleum (b. p. 40—60°) to yield a pale yellow solid, m. p. 105—110°, $[\alpha]_D^{20°}$ + 27° in chloroform (*c*, 0·28) (Found: C, 56·6; H, 5·6; CH_3·CO, 35·7; N, 7·1. $C_{38}H_{48}O_{16}N_4$ requires C, 56·0; H, 5·65; CH_3·CO, 37·0; N, 6·9%).

Conversion into Anhydrolactosephenylosazone.—*Hepta-acetyl lactosephenylosazone* (4 g.), dissolved in acetone (180 c.c.) and water (100 c.c.), was mixed with sodium hydroxide solution (44 c.c., 8%) at room temperature and kept for 21 hours. The resulting solution was neutralised with sulphuric acid and diluted with acetone until the precipitation of sodium sulphate was complete. This was removed by filtration, and the acetone by distillation. Yellow needles were deposited, which were filtered off from the hot solution; a further quantity of needles was deposited from the filtrate on standing. Recrystallisation from hot pyridine–alcohol, followed by the addition of water, gave light yellow, fan-like needles (1 g.), m. p. 231—232° (not depressed by Diels's anhydrolactosazone, m. p. 230°), $[\alpha]_D^{20°}$ − 147° in methyl alcohol (*c*, 0·18) (cf. Diels's anhydrolactosazone, $[\alpha]_D^{20°}$ − 146° in methyl alcohol; *c*, 0·19) (Found: C, 55·2; H, 6·1; N, 11·6. Calc. for $C_{24}H_{32}O_9N_4$: C, 55·4; H, 6·2; N, 10·8%).

Preparation of Anhydrolactosephenylosazone Penta-acetate.—Anhydrolactosephenylosazone (0·4 g.) was acetylated as described for the acetylation of lactosephenylosazone. On pouring into water a yellow precipitate was obtained. Rosettes of shining yellow needles were obtained by solution in warm benzene, followed by the addition of light petroleum (b. p. 40—60°) until turbidity was almost reached (yield 0·5 g.); m. p. 115—117°, $[\alpha]_D^{20°}$ − 102° in acetone (*c*, 0·4) [Found: C, 60·3; H, 5·82; CH_3·CO, 29·0 (titrn.), 28·0 (Freudenberg); N, 7·1. $C_{46}H_{46}O_{18}N_4$ requires C, 60·7; H, 5·9; CH_3·CO, 27·3; N, 7·1%]. Deacetylation of the *penta-acetate* gave the original anhydrolactosazone, m. p. 232°, $[\alpha]_D^{17°}$ − 147° in methyl alcohol (*c*, 0·2).

Acetylation of Maltosephenylosazone.—Maltosephenylosazone was acetylated as described above for lactosephenylosazone. The *product*, obtained in quantitative yield, was recrystallised from alcohol and water to yield rosettes of yellow needles, m. p. 162°, $[\alpha]_D^{20°}$ + 41° in chloroform (*c*, 0·515) (Found: C, 55·7; H, 5·6; CH_3·CO, 37·0; N, 6·8. $C_{38}H_{46}O_{16}N_4$ requires C, 56·0; H, 5·65; CH_3·CO, 37·0; N, 6·9%).

Preparation of Anhydromaltosephenylosazone.—Hepta-acetyl maltosephenylosazone (9·5 g.) was deacetylated as described above for hepta-acetyl lactosephenylosazone. A yellow precipitate (A) was again deposited in the hot solution and a further quantity of precipitate (B) in the filtrate on standing. The precipitate (A) was recrystallised in the same way as the lactose compound to give long, pale yellow needles (0·3 g.), m. p. 245—246°, mixed m. p. with anhydroglucosephenylosazone (m. p. 230—232°) 224—226°; $[\alpha]_D^{20°}$ + 58° in pyridine (*c*, 0·382) (Found: C, 57·6; H, 6·0; N, 10·9. $C_{24}H_{30}O_8N_4$ requires C, 57·4; H, 6·0; N, 11·2%).

The precipitate (B) was similarly treated to yield bright yellow, pointed plates mixed with a small quantity of the light yellow needles (0·05 g.). It was found that the needles were deposited while the recrystallisation solution was warm and separation was effected by filtration of the hot solution. Any plates adhering to the needles could be removed by washing with alcohol. The addition of a further quantity of water was sometimes necessary to ensure complete deposition of the plates (2·3 g.), m. p. 194°; mixed m. p. with maltosephenylosazone (m. p. 196—199°) 165°; $[\alpha]_D^{20°}$ + 160° in pyridine (*c*, 0·23), + 90° in methyl alcohol (*c*, 0·552), + 92° in 6 : 4 alcohol–pyridine (*c*, 0·3) (Found: C, 53·6; H, 6·3; N, 10·7. $C_{24}H_{34}O_{10}N_4$ requires C, 53·5; H, 6·3; N, 10·4%).

Acetylation of Anhydromaltosephenylosazone.—(a) *Needle form.* The needles (0·27 g.) were acetylated as described above, slight warming being necessary to obtain solution of the crystals. On pouring into water an orange-red precipitate was obtained, which defied all attempts at crystallisation. The best method of purification was solution in benzene, followed by precipitation with light petroleum (b. p. 60—80°) to give a pale fawn, amorphous *penta-acetate* (0·4 g.), $[\alpha]_D^{20°}$ + 90·7° in acetone (*c*, 0·275) [Found: C, 56·7; H, 5·6; CH_3·CO (Freudenberg), 30·0; N, 7·3. $C_{34}H_{40}O_{13}N_4$ requires C, 57·3; H, 5·6; CH_3·CO, 30·2; N, 7·9%]. All attempts to obtain a crystalline anhydro-compound or to regenerate the original material by deacetylation of the above acetate failed.

(b) *Plate form.* The plates (1·3 g.) were acetylated as described above to yield a pale yellow solid. Recrystallisation from alcohol gave an amorphous *penta-acetate* (1·8 g.), m. p. 110—112°, $[\alpha]_D^{20°}$ + 150° in acetone (*c*, 0·29) [Found: C, 56·8; H, 5·5; CH_3·CO, 30·5 (titrn.), 30·8 (Freudenberg); N, 7·5. $C_{34}H_{40}O_{13}N_4$ requires C, 57·3; H, 5·6; CH_3·CO, 30·2; N, 7·9%]. Deacetylation of the above acetate (1 g.) and treatment in the usual manner gave the original pure plates (0·25 g.), m. p. 194°, $[\alpha]_D^{18°}$ + 160° in pyridine (*c*, 0·243).

d-*Xylosazone Triacetate*, l-*Arabinosazone Triacetate, and* l-*Rhamnosazone Triacetate.*—The pure osazone (1 g.) was dissolved in pyridine (5·5 c.c.) and acetic anhydride (2 c.c.) and kept for 36 hours. The solid obtained on pouring into water was recrystallised from aqueous ethyl alcohol.

d-*Xylosazone triacetate* crystallised in clumps of needles, m. p. 116—117°, $[\alpha]_D^{16°}$ − 46° in chloroform (*c*, 0·3) [Found: C, 60·9; H, 5·9; CH_3·CO, 29·9 (Freudenberg), 27·9 (titrn.); N, 12·7. $C_{23}H_{26}O_6N_4$ requires C, 60·7; H, 5·8; CH_3·CO, 28·4; N, 12·3%].

l-*Arabinosazone triacetate* was similar in appearance to the corresponding xylose derivative; it had m. p. 114°, $[\alpha]_D^{16°}$ *ca.* + 5° in chloroform (*c*, 0·3) [Found: C, 61·2; H, 6·1; CH_3·CO, 30·0 (Freudenberg), 28·0 (titrn.); N, 12·5. $C_{23}H_{26}O_6N_4$ requires C, 60·7; H, 5·8; CH_3·CO, 28·4; N, 12·3%].

l-*Rhamnosazone triacetate* was obtained as an amorphous yellow solid, m. p. 75°, $[\alpha]_D^{18°}$ + 52° in chloroform (*c*, 0·4) [Found: C, 61·4; H, 6·0; CH_3·CO (titrn.), 28·4; N, 12·2. $C_{24}H_{28}O_6N_4$ requires C, 61·5; H, 6·0; CH_3·CO, 27·6; N, 12·0%].

Deacetylation of these compounds according to the conditions previously described gave ill-defined brownish-yellow solids which could not be obtained crystalline.

Monoanhydroglucosazone and Monoanhydrogalactosazone Diacetates.—Diels and Meyer's method (*loc. cit.*) was used to prepare monoanhydroglucosazone, m. p. 177°, $[\alpha]_D^{17°}$ − 154° in methyl alcohol (*c*, 0·45) (Found: C, 63·2; H, 6·1; N, 16·3. Calc. for $C_{18}H_{20}O_3N_4$: C, 63·5; H, 5·9; N, 16·5%), and monoanhydrogalactosazone, m. p. 217°, $[\alpha]_D^{20°}$ + 28° in methyl alcohol (*c*, 0·3) (Found: C, 63·1; H, 6·0; N, 16·2. Calc. for $C_{18}H_{20}O_3N_4$: C, 63·5; H, 5·9; N, 16·5%). Both these derivatives (1 g.) were acetylated with pyridine (8 c.c.) and acetic anhydride (3·5 c.c.) during 3 days at room temperature and the acetates were isolated by pouring into water. *Monoanhydroglucosazone diacetate* was obtained as a yellow amorphous powder, m. p. 70°,

$[\alpha]_D^{17°}$ − 125° in chloroform (*c*, 0·3) [Found : C, 62·0; H, 5·8; CH_3·CO, 21·2 (Freudenberg), 21·4 (titrn.); N, 12·8. $C_{22}H_{24}O_5N_4$ requires C, 62·3; H, 5·7; CH_3·CO, 20·3; N, 13·2%]. *Monoanhydrogalactosazone diacetate* crystallised in yellow needles, m. p. 86°, $[\alpha]_D^{18°}$ + 64° in chloroform (*c*, 0·2) [Found : C, 61·9; H, 5·8; CH_3·CO, 21·6 (Freudenberg), 21·0 (titrn.); N, 13·5. $C_{22}H_{24}O_5N_4$ requires C, 62·3; H, 5·7; CH_3·CO, 20·3; N, 13·2%].

Fructosemethylphenylosazone Tetra-acetate.—The instructions of Ofner (*Ber.*, **1904**, **37**, 3362) were followed, but the product was invariably the *methylphenylhydrazone* described below. Neuberg's method (*Ber.*, **1902**, **35**, 959), however, gave the methylphenylosazone, m. p. 156°, $[\alpha]_D^{17°}$ + 90° in pyridine–alcohol (4 : 6) (*c*, 0·4). Acetylation according to the usual method gave a yellow crystalline acetate in quantitative yield, m. p. 128°, $[\alpha]_D^{17°}$ − 435° in chloroform (*c*, 0·4), − 236° in 95% alcohol (*c*, 0·2) (cf. Engel, *J. Amer. Chem. Soc.*, 1935, **57**, 2419) (Found : C, 60·9; *H, 6·2; CH_3·CO, 30·9; N, 10·0. Calc. for $C_{28}H_{34}O_8N_4$: C, 60·6; H, 6·2; CH_3·CO, 31·0; N,* 10·1%).

Fructosemethylphenylhydrazone.—Ofner's method (*loc. cit.*) for the preparation of the osazone readily gave a colourless crystalline derivative, which on recrystallisation yielded prisms, m. p. 170°, $[\alpha]_D^{17°}$ − 253° in pyridine–alcohol (4 : 6) (*c*, 0·6) (Found : N, 10·3. $C_{13}H_{20}O_5N_2$ requires N, 9·9%).

Fructosemethylphenylhydrazone Penta-acetate.—The methylphenylhydrazone (1 g.) was kept with acetic anhydride (3 c.c.) and pyridine (6 c.c.); after 2 days the mixture was poured into water, and the solid recrystallised from 50% aqueous alcohol to yield colourless plates of the *penta-acetate*, m. p. 121°, $[\alpha]_D^{17°}$ + 86·5° in chloroform (*c*, 0·9) (Found : C, 56·0; H, 6·1; CH_3·CO, 42·8; N, 6·4. $C_{23}H_{30}O_{10}N_2$ requires C, 55·85; H, 6·1; CH_3·CO, 43·5; N, 5·7%).

Substance.	Temp.	Time (hrs.).	% CH_3·CO.
Galactosazone tetra-acetate (32·5)	−22°	0·5	22·2
	−22	1·33	21·2
	−20 → −14	2·0	23·0
	−20 → −18	2·33	25·0*
	−20 → −10	3·17	26·6
	−23 → −21	3·5	28·3
	−20 → −17	4·0	27·4
	−20 → −18	6·42	29·0
	− 4 → − 6	2·0	29·9*
	− 4 → − 6	3·0	31·9
	+ 17	2·0	33·4*
	+ 17	2·67	34·0
	+ 17	3·0	33·6
	+ 17	4·0	33·5*
Lactose octa-acetate (50·0)	−19 → −18	0·2	24·4
	−19 → −18	0·45	30·0
	−19 → −18	0·83	42·9
	−19 → −18	1·5	43·0
	−19 → −18	2·0	45·9
	−20 → −17	4·67	48·9
	+ 16	0·02	28·0
	+ 16	0·08	39·3
	+ 16	0·25	47·3
	+ 16	4·0	49·2*
Acetanilide (31·9)	+ 18	24·0	0
Methylacetanilide (28·9)	+ 18	24·0	0
Fructosemethylphenylosazone tetra-acetate (31·0)	−19	2·0	27·0
	−10	2·0	30·8
Fructosemethylphenylhydrazone penta-acetate (43·5)	−19	2·0	38·0
	− 5 → + 2	2·5	42·8
Xylosazone tri-acetate (28·4)	−12	2·0	18·0
	+17	2·0	26·0
Arabinosazone tri-acetate (28·4)	−13 → −10	2·0	20·0
	+17	2·0	28·0

Substance.	Temp.	Time (hrs.).	% CH_3·CO.
"Dianhydro-hexosazone" mono-acetate (11·8)	−20°	2·0	7·0
	−10	2·0	9·0
	+17	7·0	11·9
Lactosazone hepta-acetate (37·0)	−20	2·0	24·1
	+17	2·0	36·0
Maltosazone hepta-acetate (37·0)	−10	2·0	32·0
	+16	2·0	37·0
	+16	4·0	37·3
Glucosephenylhydrazone penta-acetate (44·8)	−10 → −15	2·0	32·0
	+16	3·0	43·4
Glucosemethylphenylhydrazone penta-acetate (43·6)	−17 → −14	0·5	22·3
	−17 → −14	1·0	34·6
	−17 → −14	2·0	37·9
	−17 → −10	4·0	39·8
	−17 → − 8	6·5	42·3
	− 0 → − 5	14·0	40·5
	+16	3·0	43·1
β-Acetylphenylhydrazine (28·7)	−20	2·0	8·0
	−4 → 0	2·0	9·0
	+17	2·0	14·0
	+17	5·0	22·7
	+17	17·0	24·5
α-Acetylphenylhydrazine (28·7)	+16	2·0	1·7
	+16	18·0	8·0
	+16	47·0	18·0
αβ-Diacetylphenylhydrazine (44·7)	−17 → −14	2·0	19·9
	+17	0·08	17·0
	+17	0·16	20·5
	+17	0·5	20·8
	+17	3·5	21·0
	+17	4·0	24·2
	+17	21·0	33·7
	+17	42·0	41·1
Benzaldehyde-α-acetylphenylhydrazone (18·1)	+17	2·0	2·3
	+17	20·0	13·0

Glucosephenylhydrazone Penta-acetate.—This derivative was prepared from glucosephenylhydrazone, m. p. 159°, $[\alpha]_D$ — 82° in water (*c*, 0·5), by the method of Behrend and Reinsberg

(*Annalen*, 1910, 377, 189). The needles had m. p. 152°, $[\alpha]_D^{17°}$ − 10·4° in pyridine (*c*, 0·5) (Found: CH_3·CO, 43·4; N, 6·0. Calc. for $C_{22}H_{28}O_{10}N_2$: CH_3·CO, 44·8; N, 5·8%).

Glucosemethylphenylhydrazone Penta-acetate.—Glucosemethylphenylhydrazone (m. p. 131°; 3 g.) prepared according to the method of Ofner (*loc. cit.*) was acetylated by the addition of acetic anhydride (6 c.c.) and pyridine (16 c.c.) during 45 minutes with constant stirring; after 12 hours the mixture was poured into cold water. The white gummy solid obtained gave, on recrystallisation from alcohol, white shining prisms of the *penta-acetate* (2·5 g.), m. p. 113—114°, $[\alpha]_D$ + 157° in chloroform (*c*, 0·5) (Found: CH_3·CO, 43·1; N, 5·9. $C_{23}H_{30}O_{10}N_2$ *requires* CH_3·CO, 43·6; N, 5·7%).

Acetyl Estimations by Direct Titration.—For these experiments 0·10—0·15 g. of material was dissolved in acetone (35 c.c.), *N*/10-sodium hydroxide (25 c.c.) added, drop by drop in the case of the experiments in the cold, and the solution, after dilution, back-titrated with *N*/10-sulphuric acid and phenol-red. Controls were carried out on the acetone used in each experiment. Experiments using the quinhydrone electrode gave almost identical results in the cases marked *. The theoretical percentage of acetyl in each compound is given in parentheses after the name in the table.

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King's Buildings, University of Edinburgh. [*Received, June 2nd*, 1937.]

NOTES.

Volumetric Determination of Semicarbazide and Aminoguanidine. By G. Stanley Smith.

These derivatives of hydrazine may be determined by an adaptation of a method for hydrazine in which potassium iodate and sodium thiosulphate are used (cf. Bray and Cuy, *J. Amer. Chem. Soc.*, 1924, **46**, 859; Kurtenacker and Kubina, *Z. anal. Chem.*, 1924, **64**, 388).

To 0·08 g., accurately weighed, of semicarbazide hydrochloride or of aminoguanidine sulphate monohydrate, dissolved in 50 ml. of water, were added 20 ml. of 5*N*-sulphuric acid, followed by 50·00 ml. of 0·1*N*-potassium iodate. The solution was kept stoppered for 3 minutes, an excess of potassium iodide added, and the total free iodine titrated at once with 0·1*N*-thiosulphate.

If the reaction (1) is assumed, then from reaction (2) it follows that the thiosulphate equival-

$$(1)\ 5NRH{\cdot}NH_2 + 4KIO_3 \longrightarrow 2I_2 \qquad (2)\ KIO_3 + 5KI \longrightarrow 3I_2$$

ent of the total iodine so formed, deducted from that of the iodate added, gives the "apparent" iodate required. This, multiplied by 1·2, gives the true iodate. Calculated on the difference in the titrations, 1 ml. of 0·1*N*-thiosulphate = 0·0008012 g. of hydrazine or 0·001877 g. of semicarbazide or 0·001852 g. of aminoguanidine.

Found, for semicarbazide hydrochloride (m. p. 173°): semicarbazide, 67·4 (Calc.: 67·3%); for aminoguanidine sulphate (m. p. 206°): aminoguanidine, 55·7 (Calc.: 56·1%).

Maselli (*Gazzetta*, 1905, **35**, i, 271) determined semicarbazide by boiling it with dilute sulphuric acid for 15 minutes, oxidising the hydrazine with excess of iodate, boiling off the iodine, and titrating the undecomposed iodate with thiosulphate. This method was found to give high results for semicarbazide hydrochloride (theoretically, 1 ml. of 0·1*N*-potassium iodate = 0·001564 g. of semicarbazide): Found, semicarbazide, 68·9, 69·3, 69·5, 69·5%.

On the other hand, when the solutions obtained by the preliminary boiling with sulphuric acid were treated in the manner first described, the iodine produced in reaction (1) not being boiled off, the results were: Semicarbazide, 67·4%; aminoguanidine, 55·7%.

Acetonesemicarbazone, treated as in the first method, was found to react (0·0542 g., 50 ml. of water, 20 ml. of 5*N*-sulphuric acid, followed immediately in the cold by 25 ml. of 0·1*N*-iodate, required 9·4 ml. of 0·1*N*-thiosulphate). Hence it would not be possible to determine acetone by adding an excess of semicarbazide and determining this excess by direct titration.—166 Wickham Chase, West Wickham, Kent. [*Received, May 19th*, 1937.]

The System Potassium Chloride–Potassium Chlorate–Water at 20°, 50°, and 75°. By Maxwell B. Donald.

This system was investigated by Winteler (*Z. Elektrochem.*, 1900, **7**, 360) for 20°, and for the conditions where the solution is saturated with chlorate but not with chloride. The results

indicate that the solubility of the chlorate decreases very rapidly at first and then is almost constant over a large variation in chloride content; however, they give no indication of the position of the invariant point where the solution is saturated with regard to both chloride and chlorate. The present investigation had as its object the determination of the invariant point, not only at 20°, but also at 50° and 75°. The points were fixed by having excess of the two salts present in solution. The following table shows the degree of accuracy obtained at 50°:

H_2O, %.	KCl, %.	$KClO_3$, %.	*d*.
67·10	28·21	—	1·2111
67·37	28·24	4·32	1·2117

A second determination of the 20° point was made between these two samples.

The chloride was estimated by Mohr's method, the chlorate by Ruff's method (*Z. anal. Chem.*, 1917, **56**, 580), and the water by direct weighing. The results are as follows:

Temp.	H_2O, %.	KCl, %.	$KClO_3$, %.	*d*.
20°	73·4	25·0	1·56	1·177
50	67·4	28·3	4·32	1·211
75	62·6	29·3	8·08	1·244

RAMSAY LABORATORY OF CHEMICAL ENGINEERING, UNIVERSITY COLLEGE, LONDON, W.C.1.
[*Received, June 10th*, 1937.]

The Conductivity of Potassium Chloride Solutions. By CECIL W. DAVIES.

IN a recent paper (this vol., p. 432) some new measurements of the conductivity of potassium chloride solutions at 18°, based on the Jones and Bradshaw standard, were compared with the measurements of Kohlrausch and Maltby. The difference (0·07%) between the figures, it was stated, "gives the difference between the new standard of Jones and Bradshaw and the older standard of Kohlrausch and Holborn for (approximately) 0·01*N*-potassium chloride, on which Kohlrausch and Maltby's measurements depended." This is misleading because, although Kohlrausch and Maltby say that their results were based on Kohlrausch, Holborn, and Diesselhorst's work, their figures are not consistent with the standard quoted by Kohlrausch and Holborn ("Leitvermögen der Elektrolyte," 1898, p. 77). Kohlrausch and Holborn give $10^6 . \kappa = 122{\cdot}5$ for a solution containing 74·59 g. of potassium chloride in 100 litres of solution at 18°, but Kohlrausch and Maltby's mean value is $10^5 . \kappa = 122{\cdot}41_5 \pm 0{\cdot}04_5$ for a solution containing 74·60 g. of the salt in 100 litres of solution at 18° (*Wiss. Abh. Phys. Tech. Reichsanstalt*, 1900, **3**, 199). Consequently, Kohlrausch and Maltby's standard is 0·08% lower than that of Kohlrausch and Holborn, and when allowance is made for this it must be concluded that conductivities based on the quoted Kohlrausch–Holborn standard are 0·15% higher than those based on the new standard of Jones and Bradshaw.

Jones and Prendergast (*J. Amer. Chem. Soc.*, 1937, **59**, 736) have recently made a direct redetermination of the conductivity of the Kohlrausch–Holborn standard solution and find the Kohlrausch value to be $0{\cdot}18_9$% too high. The agreement between these two figures must be regarded as satisfactory when it is remembered that the indirect comparison involves measurements by Shedlovsky at 25°, the data of Kohlrausch and Maltby at 18°, and measurements by the author at 18° and 25°.

It is noteworthy that the difference between the Kohlrausch–Maltby value (which is solvent-corrected) and the Kohlrausch–Holborn value corresponds approximately with the conductivity of the water used by Kohlrausch. A possible explanation of the discrepancy between the two values therefore is that Kohlrausch and Holborn intended no solvent correction to be applied in cell calibrations based on their quoted value. This is the more likely in that no correction is mentioned in Kohlrausch and Holborn's directions, nor could one be accurately calculated for a solution made up by dilution according to these authors' recommendations.

The position then is this. If Jones and Bradshaw's new standard is accepted, any (solvent-corrected) measurements based on the Kohlrausch–Holborn 0·01*N*-standard must be considered to be 0·18% too high; but Kohlrausch's later measurements on dilute salt solutions, and any measurements based on Kohlrausch and Maltby's data, such as those of Kraus and Parker on iodic acid and of Parker on hydrochloric acid, must be regarded as 0·07—0·10% too high.—BATTERSEA POLYTECHNIC, LONDON, S.W.11. [*Received, June 14th*, 1937.]

OBITUARY NOTICES.

FREDERICK BRADSHAW.

1877—1935.

FREDERICK BRADSHAW, M.A., D.Sc., Librarian of Armstrong College, Newcastle upon Tyne, died on December 29th, 1935, at the age of 58. He was a native of Leeds and received his education at Leeds Grammar School and Brasenose College, Oxford. After graduating, he studied in Germany and London, proceeding to the degree of D.Sc. at the London School of Economics.

Bradshaw was appointed Lecturer in the Department of Modern History at Armstrong College in 1904 and held this position until his appointment as Librarian in 1921.

In the field of scholarship his most important contributions were "A History of Modern England," "Self Government in Canada," and "A Social History of England." He took an active part in the work of the Historical Association and the Newcastle Society of Antiquaries, contributing several papers to the latter which have appeared in its *Proceedings* and "Archæologia Æliana."

Bradshaw is greatly missed, for all with whom he came in contact could not fail to admire his scholarship, respect his advice, and esteem his kindly nature. L. A. SAYCE.

JACK WARD DRAKE.

1914—1937.

THE death of Jack Ward Drake at the early age of twenty-two has deprived the Chemical Society of one of its youngest Fellows. He was born on July 25th, 1914, and received his general education at Heckmondwike School, Yorkshire. There he had a brilliant scholastic career and established for himself a reputation for wise and sympathetic leadership. His interest in science was early apparent and the school scientific society enjoyed a very successful period under his enthusiastic guidance.

Drake entered the University of Leeds in October, 1933, to study for an Honours degree in Chemistry. A keen student and one who regarded his work with intense seriousness he tended, in consequence, to become rather quiet and reserved. His interests, however, were far from narrow, for, in addition to his degree courses, he studied music and was an efficient member of the Officers' Training Corps. He graduated with Honours in 1936 and was elected a Fellow of the Chemical Society in the same year.

Unknown to his friends, Drake must have fought a hard battle against ill-health during the latter portion of his University career. Wishing to return to undertake post-graduate research work, he had accepted a vacation post at the Fruit and Vegetable Preservation Research Station at Campden, Gloucestershire, but a severe hemorrhage revealed advanced tuberculosis and enforced an early return to his home. In Middleton Sanatorium at Ilkley he at first made good progress towards recovery, but an attack of pleurisy intervened and he died on Sunday, April 11th, 1937. A young man of sterling character, showing considerable scientific promise, his death at the threshold of his career is a tragedy deeply regretted by all his friends. J. W. BAKER.

GEORGE INGLIS HUDSON.

1863—1936.

GEORGE INGLIS HUDSON was the son of Thomas Inglis Hudson, timber and shipping merchant, and was born at Hobart, Tasmania, on September 5th, 1863. He was educated at the Hutchens Private School, Hobart, and in 1880 came to reside in Sydney, New South Wales, where he qualified in pharmacy. He married Miss Mary Louise McCloy,

and in 1889 transferred his activities to Ipswich, Queensland, where he established an extensive practice in pharmacy and dentistry. It was here that he devised and put into operation his formula for "Hudson's Eumenthol Jubes," which are widely known throughout Australia and abroad. In 1907 he returned with his wife and daughter to Sydney, where he founded and controlled a business as manufacturing chemist under the title of "Hudson's Eumenthol Chemical Co." His residence in Sydney gave him the opportunity to take a refresher course in organic chemistry at the Sydney Technical College under the tuition of the late Henry G. Smith, with whom he later became a close associate, so much so that his name appears with that of Smith in Martindale's "Extra Pharmacopœia" in connection with eucalyptus oil.

Hudson was one of the group of students and teachers who interested themselves in the foundation of the Sydney Technical College Chemical Society in 1913, and became a member of the first Council. At one of the Society's meetings in 1916 he exhibited a specimen of pure cineole, which he was producing on a technical scale at his works by a method he had developed in collaboration with H. G. Smith.

As an earnest of his continued interest in the advancement of organic chemistry he bequeathed a sum of £1000, to be used by the University of Sydney and the Technical College for the purpose of encouraging students in the study of that branch of chemistry.

Hudson was elected a Fellow of the Chemical Society in 1917. He was a member of the Royal Society of New South Wales and of the Sydney section of the Society of Chemical Industry, as well as of the New South Wales Club, the Australian Golf Club, and the Australian Jockey Club.

He died at a private hospital in Darlinghurst, Sydney, on April 15th, 1936, and was interred in the Presbyterian section of the Waverly cemetery, the final token of respect and regard being paid by his colleagues and many of Sydney's representative citizens.

R. W. Challinor.

HOOPER ALBERT DICKINSON JOWETT.

1870—1936.

Dr. H. A. D. Jowett died in the County Hospital, Dartford, on August 10th, 1936, as the result of a motor accident. Though a Dorsetshire man by birth, being born at Dorchester on April 25th, 1870, he was educated at the Royal Lancaster Grammar School and served an apprenticeship in pharmacy in Lancaster. Thanks to the external degree system of London University, he was able to make some progress towards the London B.Sc. degree during his apprenticeship, at the end of which he was a successful candidate for one of the scholarships awarded annually by the Pharmaceutical Society in memory of Jacob Bell. After the usual course in the Society's College he took his diploma of Pharmaceutical Chemist in 1892 and the B.Sc. (London) degree in 1893, and in the following year was appointed demonstrator in the Society's Research Laboratories, under the direction of Professor (now Sir) Wyndham Dunstan.

Work on aconitine was then in progress, and the first paper in which Jowett was concerned dealt with the three interconvertible forms of aconitine aurichloride. This was followed by his thesis for the D.Sc. (London) on atisine, the non-toxic alkaloid of *Aconitum heterophyllum*. In the same year, 1895, the late Sir Henry Wellcome founded the Wellcome Chemical Research Laboratories under the direction of the late Dr. F. B. Power, and Jowett was appointed on the staff of the new laboratories; he remained there until, in 1906, he moved to Messrs. Burroughs Wellcome & Co.'s works at Dartford to organise a Works Experimental Department. He had by that time acquired a reputation as a research worker and his managing and organising abilities made him an obvious choice for the position of Works Manager to which he was appointed in 1907, and in which he was to remain for the rest of his life.

Jowett's best-known work is that on the Jaborandi alkaloids begun in 1900, when there was still considerable confusion as to the actual alkaloidal constituents of the drug and practically nothing was known regarding their constitution. His first care was to character-

ise and describe fully the principal alkaloids, pilocarpine and *iso*pilocarpine, and to confirm the existence of pilocarpidine, which is only found in one variety of the drug. In the ensuing work on the constitution of the two principal alkaloids, it was shown that the greater part of the molecule consisted of the residue of a new open-chain lactone acid, homopilopic acid (I).

$$\begin{array}{l}\mathrm{CHEt{\cdot}CH{\cdot}CH_2{\cdot}CO_2H} \\ \mathrm{CO{-}O{-}CH_2} \\ \quad\text{(I.)}\end{array} \qquad \begin{array}{l}\mathrm{CHEt{\cdot}CH{\cdot}CH_2{\cdot}C{\cdot}NMe} \\ \mathrm{CO{\cdot}O{-}CH_2 \quad CH{-}N} \\ \quad\text{(II.)}\end{array}\!\!>\!\mathrm{CH} \qquad \begin{array}{l}\mathrm{CHEt{\cdot}CH{\cdot}CH_2{\cdot}C{-\!\!-\!\!-}N} \\ \mathrm{CO{\cdot}O{-}CH_2 \quad CH{\cdot}NMe} \\ \quad\text{(III.)}\end{array}\!\!>\!\mathrm{CH}$$

In the meantime work on these alkaloids had also been started in Germany, and Pinner and Schwarz in 1902 were the first to suggest that the rest of the molecule consisted of a methylglyoxaline nucleus and to propose that *iso*pilocarpine might be represented by formula (II). This kind of structure is unique among alkaloids and has not been found outside the genus *Pilocarpus*, which belongs to a botanical family, *Rutaceæ*, remarkable for the diversity of alkaloidal types found in its genera. Jowett was able to confirm this formulation as the result of a study of the glyoxalines formed by the distillation of *iso*pilocarpine with soda lime and careful determination of the characteristics of a series of synthetic glyoxalines, and in the following year accepted Pinner and Schwarz's formula, with the qualification that the methyl group in the glyoxaline nucleus might equally well be in the alternative position as in (III). This point was settled in favour of formula (II) by Pyman in 1922, who showed that the dimethylglyoxaline formed when *iso*pilocarpine is distilled with soda lime is the 1 : 5-derivative. Jowett also observed the interconvertibility of pilocarpine and *iso*pilocarpine, a useful addition to the previously accumulated evidence that the two alkaloids are stereoisomerides. All these results have been confirmed by the synthesis, by other workers, first of pilopic and homopilopic acids and quite recently of pilocarpine and *iso*pilocarpine.

Jowett also did useful work, partly in collaboration with Pyman, in tracing the influence of changes in chemical constitution on physiological action, particularly in regard to the mydriatic action of the tropeines, and he was one of the pioneers in the chemical investigation of hormones, doing work on the constitution of adrenaline in 1904 and being associated with Barger in the synthesis of substances allied to adrenaline. Apart from these main problems he made notable contributions to the chemistry of other natural products such as the *Salix* glucosides, barbaloin, chrysarobin and cascara bark and with Pyman he investigated the interesting *iso*quinoline alkaloids of *Zanthoxylum brachyacanthum*.

During the war years Jowett was fully absorbed in strenuous efforts to meet the demand for synthetic drugs previously imported from Germany; among the successful achievements under his management was the manufacture of arsphenamine, neoarsphenamine and other complex synthetic drugs not previously made in this country. These developments were continued after the war, and the rapidity with which the manufacture of modern remedies such as insulin, ephedrine and ergometrine was undertaken is a tribute not only to Jowett's scientific acumen, but to his skill as an administrator and to his vigorous and inspiring personality.

Jowett held a commission as lieutenant in the 4th Volunteer Battalion of the Royal West Kent Regiment during the War and in recent years played a considerable part in local affairs; he was a member of the Dartford Borough Council and as Chairman of the Public Health Committee rendered great assistance in the solution of the complex problems that arise in modern municipal government. In spite of his preoccupation with administrative work and public duties, he found time to take an interest in scientific progress and he thoroughly enjoyed discussions with his friends on recent developments. He was a Freemason, an enthusiastic Wagnerian, a keen golfer, and one of the earliest devotees of motoring and to the end of his life he maintained his interest in the technical equipment of cars and his pleasure in driving. Jowett was above all a kindly and very human person; his all-round interest in human achievement did not prevent his having a few pet aversions, but even the proponents of views he disliked could always count on a fair and courteous hearing and a willingness to compromise if such were possible without sacrifice of principle.

T. A. Henry.

SIDNEY SCRIVENER NAPPER.*

THE death is announced of Sidney Scrivener Napper at the age of 57.

Educated at Owens School, Islington, he went to South Kensington in 1896 and took his diploma of Associateship of the City and Guilds Institute in 1900. While there he came under the influence of Prof. H. E. Armstrong, whose private assistant he was for a time, and of W. J. (now Sir William) Pope, to whom he was indebted for his enthusiasm for crystallography and microscopy.

After a year or two in a gas-mantle industry, he joined the chemical staff of the Royal Gunpowder Factory, Waltham Abbey, in 1901, and brought to bear with success the influences mentioned above on the investigations then in hand on cordite and its ingredients, as well as on the general work of the central laboratory. Believing that he had need of practical contact with an industrial process, he left the R.G.P.F. in 1904 and took a post with the Otto-Hilgenstock Coke Oven Co., where the work was at least strenuous.

As he had been associated with the writer in experimental work on the mode of decomposition of nitrocellulose, he returned to the R.G.P.F. for a period during which that phase of the work was completed. It will be found in the *Journal* of the Chemical Society: "The estimation of small quantities of nitrogen peroxide" (spectroscopically), p. 761, 1907, and "The evolution of nitrogen peroxide in the decomposition of gun-cotton," p. 764, 1907.

Experience with cellulose at the R.G.P.F. brought him to the notice of the late C. F. Cross, who obtained for him an appointment with Messrs. Courtauld at Coventry, in 1905. This firm was then starting the manufacture of viscose silk and the technical difficulties in production were so great as seriously to jeopardize its chances of success. It is understood that the situation was to a great extent saved by Napper who, by a suitable choice of a liquid for treating the extruded threads, gave them the necessary strength to permit of their being handled, and by attention to the conditions of storage of the material at an earlier stage overcame the difficulty of want of uniformity in the thread when it came to be dyed. The process of extrusion of a colloidal material was of course one with which he had been familiar in the cordite factory at Waltham Abbey.

Napper became chief chemist to Courtauld's in 1917, and for a few years was engaged with the Courtauld Development Department, having a laboratory in London and conducting experimental work resulting in several patents. In 1923 he retired from this and engaged in consulting work for the most part connected with developments of viscose.

After he left Coventry he lived at Bournemouth, and his friends who visited that town during the meeting of the British Association in 1919 will remember with pleasure his house and landscape gardening. For he was an enthusiastic gardener, specializing in herbaceous plants. The writer well remembers how the scent of a few heads of one of his rhododendrons perfumed the office of the Government Laboratory. The surrounding district was a fascination to him on account of the prehistoric remains throughout Dorset, and of these he had acquired much knowledge. Later, he came nearer London and lived at Woking.

Possessed of a keen and logical mind, Napper tenaciously followed his ends with enthusiasm and knowledge, and this can be said both of his research work and also of his contributions to the technology of artificial silk. He was of a reserved disposition, and was not always understood, but his intimate friends knew and appreciated him. He had artistic abilities which found their expression in the furnishing of his house and the laying out of gardens, and also in photography, in which he had expert knowledge.

He leaves a widow and two children.

R. ROBERTSON.

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DAVID SOMMERVILLE.

1864—1937.

DAVID SOMMERVILLE, who died after a short illness on January 30th last, was born in 1864, the eldest son of the late John Sommerville of Benburg, Co. Tyrone. Though settled in Ireland, the family was Scottish, descendants of a son of Sir Gautier de Sommerville, one of William the Conqueror's generals, who settled in Scotland. He was educated at a private school at Dungannon, showing exceptional ability and gaining many prizes, notably in mathematics, which always had an attraction for him. He afterwards entered Queen's College, Belfast, and obtained the B.A. degree, Royal University of Ireland, in 1895. He took the medical course there and at Middlesex Hospital, London, and graduated M.B., B.Ch., R.U.I., in 1895, and M.D. in 1897. Later, he obtained the Diploma in Public Health, University of Cambridge, and the Membership of the Royal College of Physicians, London.

Sommerville's first appointment was in 1898 as Lecturer on Physiology at Cook's School of Anatomy, Brunswick Square, London, and he was Demonstrator of Physiology at St. Thomas's Hospital, 1900—1902. In 1903 he was elected Demonstrator in the State Medicine Department, King's College, and was promoted to Lecturer in Public Health in 1905 and to Assistant Professor of Hygiene in 1913, in King's College, University of London; this post he held until the transfer of the Department to the London School of Hygiene and Tropical Medicine in 1925.

At King's College, Sommerville was in charge of the course in chemistry and the teaching required for the diploma and degrees in public health. He was an excellent teacher, and took much trouble in the instruction of his students and in the conduct of the classes. He was examiner for the Diploma and Degrees in Public Health at Edinburgh University and elsewhere on two or three occasions.

Sommerville's inclinations and bent were, however, mainly chemical, and he was much interested in the chemistry and bacteriology of disinfection, water and sewage, but his activities, particularly during the War, ranged over a variety of subjects. These included dermatology and clinical medicine—gastric disorders, involving, as they do problems of a chemical nature, were of special interest to him—and he held for short periods posts as pathologist to the Hampstead Military and Royal Herbert Hospitals, and as Medical Officer of Health at Harrow and at Coulsdon. If he had concentrated more on one or two subjects, he would doubtless have gone much farther than he did as an original investigator.

Of his published work, several papers were contributed, separately or in collaboration with the late J. T. Ainslie Walker, on the Rideal-Walker method for the standardisation of disinfectants, including suggestions for the introduction of organic matter into the test. In 1906, Professor Sommerville gained a "Society's Premium" for a paper entitled "Some Observations on the Chemistry and Bacteriology of Potable Waters," and in 1909 he was awarded the "President's Gold Medal" for a paper on "The Chemistry and Bacteriology of Sewage Purification," both at the Society of Engineers. He gave two courses of Cantor Lectures at the Royal Society of Arts, one in 1913 on "Antiseptics and Disinfection," the other in 1915 on "Foodstuffs"; the last-named contains an admirable summary of what was known at the time concerning the amino-acids of protein and of the chemical changes occurring in the digestion of proteins. A paper on the hydrolysis of vegetable oils by castor bean was contributed to the *Biochemical Journal* in 1911. He sat on numerous committees, and was a member of the Executive Committee of the British Science Guild, and for a time Honorary Secretary of its Health Committee.

Sommerville's Irish upbringing doubtless helped to form his character, with its humour and somewhat casual bearing, but he was a good friend to all who knew him intimately. He enjoyed his golf and maintained his many interests and friendships to the last, for the years dealt kindly with him, and he will be missed by a large circle, including his widow, a sister-in-law of the late Professor Meldola.

R. TANNER HEWLETT.

MICHAEL EDMUND STEPHENS.

MICHAEL EDMUND STEPHENS was the son of the late Mr. Henry C. Stephens, who for many years represented Hornsey as a Member of Parliament. His grandfather was Henry Stephens, the founder of the business of Henry C. Stephens, Ltd., and the first inventor of blue-black writing ink. Michael Stephens was educated at Rugby, and on leaving school went into the business with his father. He possessed great business aptitude and in 1918 was admitted into partnership. In 1925, the business was formed into a public company with a capital of £850,000. Stephens retired from the Board of Directors in 1926, and his death took place on February 12th, 1936.

He was elected a Fellow of the Chemical Society on December 2nd, 1897.

SYDNEY YOUNG.

1857—1937.

SYDNEY YOUNG was born at Farnworth near Widnes on December 29th, 1857. His father, Edward Young, was a Liverpool merchant and Justice of the Peace for the county of Lancashire. Young was educated privately and received his training in chemistry under Sir Henry Roscoe and Prof. Carl Schorlemmer at Owens College, Manchester, and Professor Fittig in Strasburg. He matriculated in the University of London in 1877, graduated in 1880, and was awarded the degree of D.Sc. three years later.

In 1880 the Chemical Society at Owens College was founded by the students and Young and Arthur Smithells followed Cross and Bevan as joint secretaries. It was to this society that, at Roscoe's suggestion, Young demonstrated Carnelley's discovery that ice exposed to very low pressures cannot be liquefied even by the application of great heat, and he then offered an explanation the experimental verification of which was published with Ramsay in the *Philosophical Transactions* of the Royal Society early in 1884. It seems probable that this experiment, carried out in his student days, first attracted Young's attention to a subject on which he commenced to work after his appointment in 1882 as Lecturer and Demonstrator in Chemistry under Ramsay at University College, Bristol.

There is a note in *Chemical News* (1883, 104) on a simple apparatus to show Carnelley's experiment and a further modification was devised in conjunction with Ramsay which enabled the temperature of the ice to be determined and the pressure in the apparatus to be calculated.

The joint investigation was continued, and the apparatus improved and rendered suitable for the determination of boiling points of liquids as well as the volatilising points of solids, both temperature and pressure being read directly. By means of this apparatus it was definitely proved, first, that the graph representing the vapour pressure of ice at different temperatures represents also its volatilising point under different pressures, and, secondly—as predicted by Professor James Thomson and independently by Kirchhoff—that the vapour pressure of ice, at any temperature below the triple point, is lower than that of water. This investigation was extended to other volatile solids, and in addition to such substances as ammonium chloride, chloral hydrate, etc., which undergo dissociation on vaporisation. The results were described in a series of joint papers with Ramsay on "Evaporation and Dissociation," published in the *Transactions* of the Royal Society and in those of the Chemical Society between 1884 and 1886.

For some time previously Ramsay had been engaged in investigating the vapour pressure, specific volume and critical constants of some liquids, employing a pressure apparatus similar in principle but differing in detail from that used by Andrews in his classical work on carbon dioxide. At Ramsay's invitation, Young now joined him in this research. A description of the apparatus will be found on p. 122 of Young's "Stoichiometry," 2nd Ed., 1918 (Longmans and Co.), and a model is now in the South Kensington Museum.

The thermal properties were determined of ethyl ether, methyl, ethyl, and propyl alcohols, acetic acid, and a mixture of ether and ethyl alcohol. In this work constant

temperatures were obtained by means of the vapours of liquids boiling under known pressures. The results showed that at constant volume the relation between the temperature and vapour pressure of a liquid is represented by the formula $p = bT - a$, where b and a are constants depending on the volume. It was found, however, that the relations between pressure and volume are not accurately represented by van der Waals' equation of state, although the above expression may be deduced from that equation. Later Young found that in most cases the relationship just mentioned is not strictly true except at large and possibly at very small volumes.

During these investigations Young had noticed that the value of $T \, . \, dp/dt$ at the same pressure was the same for such closely related substances as chloro- and bromo-benzene; in consequence, he made a systematic study of the vapour pressures of numerous substances previously determined by Regnault, by Ramsay and by himself. He and Ramsay found that for two substances which are not closely related, the values of $T \, . \, dp/dt$ are generally only approximately equal, and that the differences are evidently real and not due to experimental error, since the ratio between the two values for the expression remained the same at all pressures.

In the case of dissociating substances the values were usually widely different. A preliminary account of these results was communicated to the British Association in 1885, and the whole subject discussed, and other relations described, in a series of joint papers with Ramsay under the general title of "Some Thermodynamical Relations," in the *Philosophical Magazine* in 1885 and 1886. Of these, that concerned with the boiling points of different liquids at a series of equal pressures is of very general utility.

In these investigations, calling R the ratio of the absolute temperature of two liquids at any one vapour pressure, and R' the ratio at another, the relationship found was expressed by the equation $R' = R + c(t' - t)$, where c is a constant, and t and t' the temperatures of one substance corresponding to the two pressures. For closely related substances, as a rule $c = 0$, for others it is very small, but the relationship does not hold for materials whose molecules undergo either dissociation or association. At a later date, Young expressed his surprise on finding that the law did not hold accurately for the homologous series of the normal paraffin hydrocarbons.

In 1887 Ramsay succeeded Williamson in the Chair of Chemistry at University College, London, Young was appointed to the Chair at Bristol, and the partnership, which had lasted five years and during which more than thirty joint papers had been published, came to an end.

Young then commenced a systematic investigation of the vapour pressures, specific volumes, and critical constants of a series of pure liquids, for he desired to obtain further light on the relationships previously mentioned, and to test the validity of the generalisations of van der Waals regarding corresponding temperatures, pressures, and volumes. Communications on the generalisations of van der Waals and on the determinations of the critical volume were published in the *Philosophical Magazine* of 1892.

The specific volumes of liquids obtained by direct readings were found to be unsatisfactory at high temperatures, and the method Young employed in nearly all cases consisted in calculating the specific volumes of both liquid and saturated vapour from a series of readings of the volumes of liquid and vapour. For those substances which attack mercury, he devised a new method, determining the specific volumes of both liquid and saturated vapour by using sealed tubes. This method proved to be so satisfactory that it was employed for all the substances he examined.

From 1888 onwards Young investigated a large number of liquids, firstly those closely related, such as benzene and its four monohalogen derivatives, the tetrachlorides of carbon and tin, and ten aliphatic esters. At this period, however, it had become recognised that the physical properties of compounds containing a hydroxyl group, such as water, the alcohols, and acids, are abnormal in many respects. It was known that the molecule of acetic acid was associated in the vapour phase and the conclusion was reached that the molecules of all these substances are associated in the liquid state.

For these reasons, among others, Young then passed to the study of the lower members of the paraffin hydrocarbons, since he considered that they were least likely to behave

abnormally. *n*-Pentane, *n*-hexane, *n*-heptane, *n*-octane, and *iso*pentane were carefully investigated, and the last substance found to be exceptionally valuable for the complete study of the compressibility of liquid and unsaturated vapour, as well as the vapour pressure and specific volumes. A series of papers on the thermal properties of these hydrocarbons was published between 1894 and 1899, some in collaboration with G. H. Thomas and others with J. Rose Innes.

The study of these hydrocarbons naturally led Young to consider the possibility of separating a number of substances from American petroleum, but all attempts with the apparatus then available proved fruitless.

The preparation of the various liquids used in his researches had of necessity drawn Young's attention to the problem of distillation, and an excellent summary of the advances he made in this somewhat neglected subject will be found in his article on "Distillation" in Sir Edward Thorpe's "Dictionary of Applied Chemistry." In conjunction with G. L. Thomas in 1897 he devised a dephlegmator on the principle of that which forms part of the Coffey still, and this, in conjunction with a regulated temperature still-head, enabled them to prepare pure specimens of *n*- and *iso*-pentane from the lower-boiling fractions of petroleum. It was also found that American petroleum, like Russian, contains penta- and hexa-methylenes and their methyl derivatives. In fact, Young showed that the composition of American petroleum is similar to that of the Russian and Galician oils, the only difference being the relative proportions of paraffins, polymethylenes, and aromatic hydrocarbons present. The thermal constants of hexamethylene, di*iso*propyl, and di*iso*-butyl were described with Miss Emily C. Fortey in 1899 and 1900. *n*-Hexane, prepared by the fractionation of benzene-free petroleum, cannot be separated from *iso*hexane and methyl-pentamethylene by fractional distillation. In 1898, however, the action of fuming nitric acid on different classes of hydrocarbons had been investigated in collaboration with F. Francis, and as a result it was found that, through the agency of this acid, the two other constituents could be removed, and pure *n*-hexane isolated from petroleum for the first time. The action of chlorosulphonic acid on the paraffins was investigated in 1899. Many years later (1933), Young received a letter from the Petroleum Division of the American Chemical Society expressing their high appreciation of his work on distillation, on the composition of petroleum, and on the determination of the physical properties of numerous hydrocarbons.

In 1905 the question had been raised as to whether the vapour pressure of a pure substance is independent of the relative volume of liquid and vapour. Young discussed this in a paper published in the Royal Dublin Society's *Journal* (1906, **11**, 89). Data from previous communications showed conclusively that when a substance is free from all impurities, including dissolved air, the vapour pressure remains constant irrespective of the relative volumes of liquid and vapour.

Young discussed the "Law of Cailletet and Mathias and the critical density" in a communication to the *Philosophical Magazine* in 1900, and a controversy arose later regarding the condition of matter at the critical point, some contending that the critical temperature was not a true constant and that a substance at the critical state was not really homogeneous. The evidence of Young's prolonged investigations was all in favour of what may be regarded as the orthodox view that the densities of liquid and vapour become identical at the critical point. The critical density is very difficult to determine experimentally, but Cailletet and Mathias arrived at the conclusion that the mean of the densities of any substance, in the state of liquid and saturated vapour, plotted against the temperature, fall on a straight line, $S_t = S_0 + \alpha t$, where S is the density or specific gravity. Young found that this relation was strictly true for *n*-pentane, but that in most cases there was very slight curvature, or $S_t = S_0 + \alpha t + \beta t^2$. The ratio of the actual to the theoretical density at the critical point was found to be much higher than would be required by the van der Waals formula and to range from 3·68 to 3·86 for the normal substances investigated. There was also found to be a definite connection between this ratio and both the constant β in the Cailletet–Mathias modified formula and other physical constants. The experimental data for the densities of saturated vapour are necessarily less accurate at low temperatures than at high, but in 1908 a theoretical method of correction was devised by Young, and the vapour

pressures, specific volumes (densities), and critical constants of the thirty pure substances previously investigated were carefully revised, and the complete data published in 1910 in the *Scientific Proceedings* of the Royal Dublin Society.

Kopp concluded in 1842 that a constant difference in chemical composition is accompanied by a constant difference in boiling point, and two years later, took 19° as the true difference for an addition of CH_2 in any homologous series. This erroneous conclusion was due to the fact that most of the substances he examined were characterised by molecular association. Young suggested in his presidential address to the chemical section of the British Association at Cambridge in 1904, that in order to ascertain the normal behaviour of pure substances it is advisable at first to examine only those whose molecules show no sign of association in either the gaseous or the liquid state. As regards the boiling points of the *n*-paraffins at 760 mm., it was known that the rise in temperature for an addition of a CH_2 group was very far from constant. James Walker and later Ramage suggested formulæ based on the number of carbon atoms in the molecule, and Young in his address pointed out that the difference in temperature, Δ, might be regarded as a function of the temperature only, and suggested the formula $\Delta = 144{\cdot}86/T^{0{\cdot}0148\sqrt{T}}$. This formula gives better results than those of Walker and Ramage. Moreover, it was found to be applicable with fair accuracy, not only to the *n*-paraffins, but also to any two consecutive members of any homologous series provided that the molecules of each substance contain at least one CH_2 group united to two carbon atoms, and further, that there is no molecular association.

This relationship, and that between critical temperature and boiling point, was again discussed by Young in 1916 (Royal Dublin Society) and 1928 (*Proceedings* of the Royal Irish Academy). He pointed out that the general formula $\Delta = A/T^{B\sqrt{T}}$ is applicable, as far as data are available, to all the *n*-paraffins from C_3H_8 to $C_{35}H_{72}$, under all pressures from 11 mm. to 20,000 mm. The constants A and B depend on pressure and methods for calculating their values are given in these papers. Tables are also given of the observed boiling points at a series of pressures of all the *n*-paraffins up to $C_{35}H_{72}$, and the boiling points calculated by three different methods, together with the most probable values derived from those observed and calculated.

This sketch of Young's investigations cannot be concluded without again alluding to the problem of fractional distillation in which he did so much pioneering work. His skill in glass blowing, gained when a student at Strasburg, was of inestimable value to him in this work, since it enabled him to construct various forms of still-heads. The efficiencies of these were compared in 1899 and the economy in material and time effected by using the most efficient was stressed in various papers. An account of this work, published under the title " Fractional Distillation " by Macmillan and Co. in 1903, is now out of print. The more recent edition " Distillation Principles and Processes," 1922, written in collaboration with Col. E. Briggs, T. H. Butler, T. H. Durrans, the Hon. F. R. Henley, James Kewley, and J. Reilly, is greatly enlarged and extended by the addition of chapters on the distillation of petroleum, coal tar, alcohol, etc., each written by experts.

The study of the vapour pressures and boiling points of mixed liquids (Part I appeared in the *Transactions* of the Chemical Society for 1902) led to the discovery of new binary (azeotropic) mixtures of constant boiling point, and it was found that ternary azeotropic mixtures of the lower alcohols, except methanol, with benzene or *n*-hexane and water could also be prepared. This enabled Young to devise a new method for the dehydration of ethyl alcohol by distillation with benzene, which was first adopted by the firm of Messrs. Kahlbaum of Berlin, and later by others.

By far the greater part of Young's work (he published over 100 papers in all) was carried out during the 21 years that he spent in Bristol. There the amount of teaching and administration was small, and he had ample time for experimental work. He was 46 when in 1903 he was invited to succeed Emerson Reynolds in the Chair of Chemistry at Trinity College, Dublin. This appointment involved a large increase in his administrative and teaching duties, his lectures being attended by the numerous students of the flourishing medical school, as well as by those taking courses in engineering and experimental science.

It was inevitable that these increased responsibilities should reduce his output of original

work, but his interest in it had not diminished, and from time to time he published papers, some of which are alluded to above, as well as the two works on distillation and stoichiometry.

During the War and immediately after, Young was compelled to undertake an amount of work which would have severely taxed the strength of a much younger man. The medical and engineering schools very largely increased in numbers, and Young was always meticulously careful in the routine work of examinations. But in addition to his greatly augmented duties at Trinity College he was one of the Vice-Presidents of the Chemical Society from 1917 to 1920, a member of the Advisory Council of the Department of Scientific and Industrial Research from 1920 to 1925—in these capacities he made over a hundred journeys to England—and President of the Royal Irish Academy from 1921 to 1926, filling with distinction a position which has been occupied by many famous men and in which " his tact, kindliness and known moderation did much to ease a difficult period of transition."

Professor Bailey writes of Young's lectures at Trinity College after the war :—" When the College halls were once more filled with students, the writer was one among the boisterous crowd who, freed from sterner discipline, flocked into the Department of Chemistry. They found there a Professor who lectured with extreme clarity, who illustrated his lectures by blackboard drawings which were the work of an artist (which indeed he was), and who, above all, set an example of old-world courtesy which made the deepest impression on those who experienced it."

Shortly before his retirement in 1928, after a quarter of a century of service in Dublin, Young was the recipient of an address from over two hundred of his friends, former pupils, and those who were acquainted with his work. The signatures came from all over the world and among those who took a prominent part in this act of recognition were Dr. W. R. G. Atkins and Professor J. Timmermans.

When as a young man Young went to Owens College, the first friend he made was Charles Kimmins, now well known as an authority on psychology and education. Dr. Kimmins remained his best friend all his life, and in 1896 Young married his sister, Grace Martha Kimmins. In 1897 they had twin sons born to them, Sydney Vernon, who passed high into the Royal Academy at Woolwich and gave promise of making for himself a brilliant career in the Royal Engineers, but was killed in action before Ypres in 1915, and Charles Edgar, who came safely through the war and is now headmaster of Lincoln School and headmaster elect of Rossall.

Young was a man who made lasting friendships. He and Mrs. Young found Dublin society very congenial and their house, first in Raglan Road and later in Clyde Road, became an intellectual centre. On his retirement, they returned to the neighbourhood of Clifton, Bristol, where he was able to enjoy his favourite hobby of gardening. In these last placid and happy years he renewed many old friendships that he had never forgotten. Towards the end his thoughts turned more to early days, and it gave him very great pleasure when he was made President of the Old Students Association of Owens College, Manchester, a few months before he died. He passed away in his 79th year, after a very brief illness, on April 9th, 1937, and is survived by his wife and son.

Young was elected to the Royal Society in 1893, received the honorary degree of Sc.D. Dublin in 1905, the D.Sc. of his old college, now the University of Bristol, in 1912, and the M.A. of Dublin in 1921.

My thanks are due to Mr. C. E. Young for the loan of many of his father's notes, and to Professor Kenneth C. Bailey for information about his life in Dublin.

F. Francis.

269.—*The Elimination of the Phosphate Radical in Qualitative Analysis.*

By L. W. N. GODWARD and A. M. WARD.

A NUMBER of processes have been described to overcome interference of the phosphate radical in qualitative inorganic analysis (for references, see Smith, J., 1933, 253; *Ann. Reports*, 1936, **33**, 451); Smith (*loc. cit.*) also developed an improved scheme, based on precipitation from a buffered formate solution (see also Tower, *J. Amer. Chem. Soc.*, 1910, **32**, 953; Schulze, *Centr.*, 1861, 3). No process appears to have been described in which phosphate is eliminated as ammonium phosphomolybdate; the present paper contains a fairly concise scheme based on this, and includes the detection of calcium as its molybdate. Ammonium molybdate may not have been used in this way previously, for molybdenum is often considered among the "rarer" elements; ammonium molybdate is, however, less expensive than many compounds which, by usage, are regarded as "common." Nevertheless, in the procedure which follows, only "common" elements in the classical schemes of analysis are included.

Phosphate Separation.

After Group II, boil off H_2S, oxidise with concentrated HNO_3 (1—2 ml.). To one part (½ ml.) add concentrated HNO_3 (1 ml.) and ammonium molybdate solution (4—5 ml.) and warm: yellow precipitate = *Phosphate*. To a second portion (½ ml.) add ammonium chloride (0·5 g. in 3 ml. water) and ammonia: if no precipitate forms, or a precipitate soluble in excess, proceed to zinc group with main bulk of solution; if precipitate is insoluble in excess of ammonia, to main bulk of solution add a few ml. of dilute H_2SO_4 and about 1 g. of $(NH_4)_2SO_4$. Boil and filter.

Precipitate.—$SrSO_4$ and $BaSO_4$. Boil for 3—4 mins. with 10 g. of Na_2CO_3 and 50 ml. of water. Filter and neglect filtrate. Dissolve ppt. in acetic acid, filter (neglect insol. part, $BaSO_4$). Add K_2CrO_4. Filter.

- *Precipitate.* Yellow = *barium.*
- *Filtrate.* Add dil. H_2SO_4. White ppt. = *strontium.*

See Note 1.

Filtrate.—Dilute to about 25 ml. with water, add 5 ml. of conc. HNO_3 and 5 g. of NH_4NO_3. Boil, and stir in powdered ammonium molybdate until present in excess (see Note 2). Boil for 5 mins., filter, and reject ppt. Heat a small portion of filtrate with ammonium molybdate to ensure that all phosphate is removed. To the cooled filtrate, add NH_4OH (*d* 0·880) dropwise with cooling until present in very slight excess. Filter.

- *Precipitate.—Ferric, aluminium,* and *chromium hydroxides.* Confirm by usual group procedure. See Note 3.
- *Filtrate.*—Make ammoniacal, and pass H_2O. Filter, and wash ppt. well with hot water.
  - *Precipitate.—Zinc, cobalt, nickel,* and *manganese sulphides.* Confirm by usual group procedure. See Note 4.
  - *Filtrate* (orange).—Acidify with HCl, boil off H_2S, filter. Reject ppt. of molybdenum sulphide. To filtrate, add sodium perborate and sodium hydroxide solution. Boil until solution colourless, and continue boiling for a few minutes to destroy excess perborate (see Note 5). Acidify with HCl, boil, filter, make ammoniacal, add 5 g. of NH_4OAc and 10 ml. of ammonium molybdate solution.* Boil gently for 10 minutes. Filter.
    - *Precipitate.*—White $CaMoO_4$. Confirm *calcium* by dissolving ppt. (readily) in hot dilute sulphuric acid, and reprecipitating by addition of ammonia and ammonium oxalate. See Note 6.
    - *Filtrate.*—Add solution of *p*-nitrobenzeneazoresorcinol, followed by NaOH until colour of dye changes. Blue gelatinous ppt. = *magnesium.*

To test for sodium and potassium: proceed by the usual group separations adopted when phosphate is absent, and examine for these two metals in the usual way.

* A 6% solution of ammonium molybdate in dilute ammonia.

Notes on the Procedure.—(1) Barium and strontium are precipitated before the addition of considerable quantities of ammonium salts, which markedly increase the solubilities of the two sulphates. In presence of large amounts of calcium, some calcium sulphate may be precipitated at this stage; it does not, however, interfere with the confirmatory tests for barium and strontium, and sufficient will remain in solution for the subsequent precipitation of calcium molybdate.

(2) Powdered ammonium molybdate is used on account of the large proportion needed to precipitate the phosphate radical [1 g. PO_4''' = 22·15 g. $(NH_4)_6Mo_7O_{24},4H_2O$]. With this in view, if for no other reason, large amounts of substance should not be taken for analysis; unless traces are being sought, 0·2 g. of material is usually sufficient.

Boiling for 5 minutes serves, not only to complete the precipitation of phosphomolybdate, but also to remove any molybdic acid which might be precipitated during subsequent heating. The precipitation of the phosphate, and indeed most of the reactions in the scheme, can conveniently be carried out in 100 ml. beakers. Excess of molybdate is clearly denoted by the presence of white, insoluble molybdate, mixed with the yellow phosphomolybdate.

(3) Concentrated ammonia is used for the precipitation of the iron group in order to avoid

excessive dilution, but it is added only in the slightest excess. The solution is kept cold to *prevent possible precipitation of calcium as molybdate.*

(4) Adsorption of molybdenum compounds on the precipitate of zinc, cobalt, nickel, and manganese sulphides is sometimes tenacious. Prolonged passage of hydrogen sulphide, with consequent reduction of the molybdate solution, and increased adsorption, should be avoided. It is occasionally best to dissolve the sulphides and reprecipitate them.

(5) Before testing for magnesium, hydrogen sulphide must be removed, as it decomposes *p*-nitrobenzeneazoresorcinol. It is also best to oxidise the coloured molybdenum compounds to colourless Mo^{VI}, for the formation of the blue lake is more easily observed in a colourless solution.

(6) Calcium is dealt with separately as molybdate, a point which we consider to be of considerable value. The presence of ammonium acetate diminishes the rate of precipitation of calcium molybdate and amounts larger than 5 g. should be avoided. Its presence is, however, necessary to prevent precipitation of molybdic acid.

Remarks.—During the development of the scheme, the precipitation of magnesium, zinc, cobalt, and nickel in presence of molybdenum by means of oxine in ammoniacal solution, was examined (Fleck and Ward, *Analyst*, **1933**, **58**, 388); it was found, however, to be unsatisfactory as a qualitative procedure.

Test analyses have been made of mixtures containing selections of all the elements considered in various proportions; in all cases the procedure afforded good qualitative separations. Traces were not usually sought, for precipitations must be carried out from solutions more dilute than those used in this scheme if adsorption by precipitates is to be avoided.

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270. *β-Asarone.*

By B. SANJIVA RAO and K. SUBRAMANIAM.

IT was recorded (Kelkar and Rao, *J. Indian Inst. Sci.*, 1934, **17**, *A*, 26) that the main constituent of the oil from the roots of *Acorus Calamus*, Linn. was a liquid phenolic ether, which gave asaronic acid on oxidation with potassium permanganate and polymerised to parasarone on treatment with arsenious acid. The ether, which differed from asarone, $C_6H_2(OMe)_3$·CH:CHMe, in that it could not be obtained crystalline, was at first regarded as the allyl isomer (*Current Sci.*, **1935**, 552), but asarone and this liquid ether, β-asarone, are now shown to be *cis-trans*-isomerides.

This conclusion is based mainly upon the following considerations: (i) Reduction of the two isomerides yields 2 : 4 : 5-trimethoxypropylbenzene, giving on nitration 4-nitro-2 : 5-dimethoxypropylbenzene. (ii) On bromination, asarone gives a crystalline dibromide, m. p. 82—83°, whereas β-asarone yields a liquid dibromide with a trace of a crystalline dibromide, m. p. 82—83°, identical with that prepared from asarone (Széki, *Ber.*, **1906**, **39**, 2420); from both dibromides the same diasarone monobromide, m. p. 101°, can be prepared. (iii) Oxidation of the two asarones with mercuric acetate in ethereal solution gives two *glycols* (compare Balbiano, *Gazzetta*, **1906**, **36**, [i], 283) which on distillation under diminished pressure yield 2 : 4 : 5-trimethoxy-β-ketopropylbenzene and a crystalline *compound*, $C_{24}H_{32}O_8$, m. p. 204—205°; the latter substance is formed also if the glycols are digested with acetic anhydride. (iv) With nitrous acid both asarones give asarone-ψ-nitrosite and 2 : 4 : 5-trimethoxynitrobenzene, the identity of the former being confirmed by the preparation from it of 2 : 4 : 5-trimethoxyphenylmethylglyoxime peroxide and β-nitroasarone (Bruckner, *J. pr. Chem.*, **1933**, **136**, 268).

β-Asarone can be converted into asarone by fusion with potassium hydroxide at 210—220° or by heating in alcoholic solution with a small quantity of selenium dioxide for ½ hour. If the heating is prolonged, a complex mixture of products is formed from which 2 : 5-dimethoxypropenylbenzene has been isolated. Other reagents, which usually cause isomerisation, had no action.

The isomerides have the following physical constants :

	M. p.	B. p.	$d^{30°}_{30°}$.	$n^{30°}_{D}$.	$[R_L]_D$.
Asarone	62—63°	167—168°/12 mm.	1·112	1·5683	62·7
β-Asarone	—	162—163°/12 mm.	1·082	1·5552	62·2

No deduction as to configuration can safely be drawn from these figures, for Auwers (*Ber.*, 1935, **68**, 1346) has shown that the Auwers–Skita rule does not hold in the styrene series.

Experimental.

β-*Asarone*, separated from calamus oil by repeated fractionation, was a pale yellow oil having the constants given above. The colour was not removed by evaporation in a Hickmann still at 70—80°. As with asarone, concentrated hydrochloric acid gave a blue colour and caused polymerisation. If β-asarone (10 g.) was added gradually to potassium hydroxide (100 g.) and water (10 c.c.) at 200° and the temperature was slowly (15 mins.) raised to 220°, acidification of the melt gave asarone, m. p. 62—63°.

Action of Selenium Dioxide on β-*Asarone*.—(a) A mixture of β-asarone (70 g.), alcohol (100 c.c.), and selenium dioxide (10 g.) was heated on the water-bath for ½ hour. The filtered solution was poured into water, the oil dissolved in ether, and the dried ethereal extract evaporated; the residue partly crystallised, and distillation gave asarone (60 g.).

(b) A mixture of β-asarone (20 g.), alcohol (50 c.c.), and selenium dioxide (5 g.) was boiled for 5 hours. The product isolated by ether in the usual manner gave an oil, which on distillation under 8 mm. gave two fractions: (i) b. p. 140—145°, $d^{30°}_{30°}$ 1·052, $n^{30°}_{D}$ 1·5451; (ii) b. p. 145—150°. From the former, a *picrate* was prepared, crystallising from alcohol in orange-red feathery leaflets, m. p. 87° (Found : N, 10·1. $C_{11}H_{14}O_2,C_6H_3O_7N_3$ requires N, 10·3%). Decomposition of the picrate with alkali gave 2 : 5-dimethoxypropenylbenzene, b. p. 128—129°/4 mm., $d^{30°}_{30°}$ 1·041, $n^{30°}_{D}$ 1·5548 (Found : C, 74·3; H, 7·8. Calc. for $C_{11}H_{14}O_2$: C, 74·1; H, 7·9%). The *nitrosite*, m. p. 118°, was a pale yellow powder (Found : N, 10·8. $C_{11}H_{14}O_5N_2$ requires N, 11·0%). Reduction of the ether with sodium and alcohol gave 2 : 5-dimethoxypropylbenzene, characterised by the preparation of the nitro-derivative, m. p. 64°.

Reduction of β-*Asarone*.—β-Asarone (10 g.) in alcohol (150 c.c.) was reduced with sodium (10 g.), the recovered ether being treated twice more with sodium under similar conditions. 2 : 4 : 5-Trimethoxypropylbenzene, so obtained, had b. p. 128—128°/6 mm., $d^{30°}_{30°}$ 1·024, $n^{30°}_{D}$ 1·5079, and a product having the same constants was obtained by the reduction of asarone. The identity of the two ethers was confirmed by nitration to 4-nitro-2 : 5-dimethoxypropylbenzene, m. p. 64° (Found : N, 6·4. Calc. for $C_{11}H_{15}O_4N$: N, 6·2%).

Bromination of β-*Asarone*.—To β-asarone (5 g.) in dry ether (20 c.c.) cooled to −20°, bromine (4 g.) in carbon disulphide (6 c.c.) was added. Removal of the solvent gave a crystalline dibromide (0·4 g.), m. p. 82—83°, the main product being an oil. Bromination of asarone under similar conditions gave a solid dibromide (7 g.), m. p. 82—83° (Found : Br, 43·1. Calc. for $C_{12}H_{16}O_3Br_2$: Br, 43·4%). To a solution of the solid or liquid dibromide (5 g.) in dry benzene (150 c.c.), cooled in ice, copper powder was added, and the mixture kept for 24 hours. The filtered solution was concentrated, whereupon diasarone monobromide (1·5 g.), m. p. 123°, crystallised, the yield being the same from both dibromides. Reduction of the monobromide in alcoholic solution with zinc dust gave diasarone, m. p. 100—101° (compare Széki, *loc. cit.*, p. 2423).

Action of Nitrous Acid on β-*Asarone*.—To a cooled (ice-salt) solution of β-asarone (5 g.) in ether (50 c.c.) containing sodium nitrite (20 g.) in suspension, sulphuric acid (20%; 30 c.c.) was added during 5 hours. After standing overnight, the crystalline asarone-ψ-nitrosite (3 g.), decomp. 130°, which had separated, was collected (Found : N, 10·1. Calc. for $C_{12}H_{16}O_6N_2$: N, 9·8%). Digestion of the ψ-nitrosite with methyl alcohol gave 2 : 4 : 5-trimethoxyphenylmethylglyoxime peroxide, m. p. 155° (Found : N, 10·2. Calc. for $C_{12}H_{14}O_6N_2$: N, 10·5%); and by the action of alcoholic potassium hydroxide β-nitroasarone, m. p. 101°, was obtained.

Evaporation of the ethereal solution from which the ψ-nitrosite had separated gave a resin (1·2 g.), which crystallised from alcohol in needles, m. p. 130°, identified as 2 : 4 : 5-trimethoxynitrobenzene. The same derivatives, in approximately similar yields, were prepared also from asarone.

Action of Mercuric Acetate on β-*Asarone*.—β-Asarone (25 g.) in ether (200 c.c.) was mixed with a solution of mercuric acetate (100 g.) in water (400 c.c.). After 24 hours' standing at room temperature with occasional shaking, 75 g. of mercurous acetate had separated, and 12 g. more separated after a further 12 hours, the ethereal layer, which was initially yellow, having then be-

come colourless. The ether was separated, and the aqueous solution extracted twice with chloroform. The combined residue (26 g.), remaining after the evaporation of the solvents, contained some dissolved mercury salts. The mercury was removed with hydrogen sulphide, and α-2 : 4 : 5-*trimethoxyphenyl*-β-*methylethylene glycol*, a viscid oil, after remaining for some days in a vacuum, had $d_4^{50°}$ 1·218, $n_D^{50°}$ 1·5330 (Found: C, 59·1; H, 7·6. $C_{12}H_{18}O_5$ requires C, 59·5; H, 7·4%). The *diacetate* was obtained when a mixture of the glycol (5 g.), acetic anhydride (25 c.c.), and phosphoric acid (0·3 c.c.) was kept below 40° for 2 hours. After removal of the excess of acetic anhydride and a small quantity of the bimolecular compound, m. p. 204—205° (see below), the liquid diacetate was analysed [Found: OAc, 23·3. $C_{14}H_{16}O_5(OAc)_2$ requires OAc, 23·9%].

On distillation of the glycol under 4 mm., a red oil, b. p. 170—230°, was obtained, which solidified. Trituration with ether left undissolved a *substance* which crystallised from alcohol in rhombic prisms, m. p. 204—205° [Found: C, 63·6; H, 7·6; *M* (in dioxan), 460. $C_{24}H_{32}O_8$ requires C, 64·3; H, 7·1%; *M*, 448]. This substance was obtained in quantitative yield on digestion of the glycol with acetic anhydride. Evaporation of the ether from which the dimeride had been separated left an oil which partly crystallised. After purification through its semicarbazone, m. p. 157—158° (Found: N, 14·7. Calc. for $C_{13}H_{19}O_4N_3$: N, 14·9%), 2 : 4 : 5-trimethoxy-β-ketopropylbenzene, m. p. 47—48°, was obtained.

Treatment of asarone with mercuric acetate under similar conditions gave an isomeric glycol, $d_4^{50°}$ 1·228, $n_D^{50°}$ 1·5415, which gave on distillation the dimeride, m. p. 204—205°, and 2 : 4 : 5-trimethoxy-β-ketopropylbenzene.

The Indian Institute of Science, Bangalore. [*Received, May 28th, 1937.*]

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271. *The Resolution of* cis- *and* trans-*Norcaryophyllenic Acid.*

By H. N. Rydon.

Synthetic *cis*- and *trans*-norcaryophyllenic (3 : 3-dimethyl*cyclo*butane-1 : 2-dicarboxylic) acids have been resolved into their optical isomerides. The synthetic *d*-*trans*-acid has been shown, by mixed m. p., to be identical with the *d*-norcaryophyllenic acid obtained by oxidation of caryophyllene. The bearing of this identity on the stereochemistry of caryophyllene is discussed and it is pointed out that the widespread assumption that natural products necessarily possess the most stable configuration is without experimental foundation.

As a complement to the synthesis of the *dl*-norcaryophyllenic acids (J., 1936, 593) it was necessary to undertake the resolution of both the *cis*- and the *trans*-acid in order to establish the stereochemical configuration of the *d*-norcaryophyllenic acid obtained as a primary product in the oxidation of caryophyllene (Evans, Ramage, and Simonsen, J., 1934, 1806).

Synthetic *dl*-*cis*-norcaryophyllenic acid was resolved by means of its neutral cinchonidine salt. In this way d- and l-cis-*norcaryophyllenic acids* were obtained as plates, m. p. 165°, $[\alpha]_{5461}^{20°}$ + 4·9° and − 5·9°, respectively; they differed very considerably in appearance from the active acid derived from caryophyllene.

Synthetic *dl*-*trans*-norcaryophyllenic acid was resolved by means of its neutral brucine salt. The d- and l-trans-*norcaryophyllenic acids* so obtained had m. p. 123—126° and 126°, and $[\alpha]_{5461}^{18°}$ + 122·2° and − 129·0°, respectively. They crystallised from water in aggregates of prisms, very similar in appearance to the *d*-norcaryophyllenic acid of Evans, Ramage, and Simonsen (*loc. cit.*), which had m. p. 125—127°, $[\alpha]_{5461}$ + 137°. A mixture of the synthetic *d*-*trans*-acid with an authentic specimen of this material (m. p. 125—126°) melted at 123—126°. (This mixed m. p. has been independently confirmed by Professor Simonsen.) It is therefore to be concluded that the active norcaryophyllenic acid isolated from the oxidation experiments is a *trans*-acid and not a *cis*-acid as was formerly supposed.

Whether this conclusion may be regarded as indicating that the 0 : 2 : 4-*bicyclo*octane system in caryophyllene has the *trans*-configuration must remain an open question. It seems likely that inversion during the oxidation process would give rise to some *dl*-acid, whereas none was isolated from the oxidation product; for this reason inversion may be considered unlikely. This, however, is not a conclusive argument, since Δ^3-carene gives, on oxidation, acids having both the *cis*- and the *trans*-configuration (for references

see Simonsen, "The Terpenes," 1932, Vol. II, p. 56 *et seq.*). It is noteworthy, however, that in systems of this type, in which a *cyclo*hexane ring is fused in the 1 : 2-position to a smaller ring, the strain in the *trans*-modification may be considerably relieved by the adoption of the Z-configuration by the *cyclo*hexane ring. Furthermore, it is desirable to point out that the widespread tacit assumption that natural products *necessarily*, or *even probably*, possess the least strained or most stable configuration seems to be unsupported by any experimental evidence; indeed, the synthetic work of Ruzicka, Koolhaas, and Wind (*Helv. Chim. Acta*, 1931, **14**, 1151, 1171) shows that the sesquiterpenes of the selinene class belong to the *cis*-decalin series, which has been shown by measurement of heats of combustion (Roth and Lassé, *Annalen*, 1925, **441**, 48) to be the less stable form.

EXPERIMENTAL.

ββ-Dimethyl-δ-valerolactone (J., 1936, 594) was converted into ββ-dimethyladipic acid by the following improvement of Blanc's method (*Bull. Soc. chim.*, 1908, **3**, 291):

Ethyl δ-bromo-ββ-dimethylvalerate. 100 G. of ββ-dimethyl-δ-valerolactone were dissolved in 500 c.c. of absolute alcohol, and the ice-cooled solution saturated with dry hydrogen bromide. The solution was kept overnight, poured into 2 l. of water, and extracted with ether. The extract was washed with sodium carbonate solution and water, dried, and distilled, yielding 173 g. (93%) of the pure bromo-ester, b. p. 89—90°/1·8 mm.

ββ-Dimethyladipic acid. 667 G. of the above bromo-ester were added to a suspension of 398 g. of AnalaR potassium cyanide in 450 c.c. of water containing 66 c.c. of acetic acid and 66 g. of sodium iodide. 1700 C.c. of rectified spirit were added, and the whole refluxed on the water-bath for 7 hours; 1325 c.c. of 40% aqueous potassium hydroxide were then added, and the refluxing continued overnight, after which the alcohol was distilled off and the residue boiled under reflux for a further 30 hours.

The dark product was boiled with norit, acidified, diluted to 5 l. with water, and filtered from the insoluble tar. The filtrate was thoroughly extracted with ether, and the residue from evaporation of the dried extract was treated with an excess of sodium carbonate solution. Extraction with ether, followed by drying and distillation, gave 70 g. of recovered ββ-dimethyl-δ-valerolactone, b. p. 90—91°/1·5 mm. The residual sodium carbonate solution was then acidified, and extracted with ether, evaporation of the dried extract yielding a hard cake of the crude acid (253 g.). This was crystallised from chloroform (300 c.c.) and light petroleum (b. p. 60—80°; 500 c.c.), yielding 233 g. (48%) of almost pure ββ-dimethyladipic acid, m. p. 86—87°.

Ethyl cyanonorcaryophyllenate. Despite many variations in the experimental procedure it was not found possible to devise conditions for obtaining this substance in a pure state. The bulk of the material used was obtained by the following modification of the procedure previously described. 205 G. of ethyl αα'-dibromo-ββ-dimethyladipate were stirred overnight under reflux on the water-bath with 95 g. of pure sodium cyanide in 200 c.c. of absolute ethyl alcohol. The dark brown product was poured into ether, the solution filtered, washed with calcium chloride solution, dried over calcium chloride, and distilled. The product (143 g.; b. p. 143—160°/3·5 mm.) gave a strongly positive reaction for bromine, and was similarly treated once more with 55 g. of sodium cyanide in 150 c.c. of absolute alcohol. On working up in the above manner, 77 g. of *cyano-ester*, b. p. 133—136°/1·5 mm., were obtained; although giving only a weakly positive test for bromine, the product was far from pure (Found: C, 52·3; H, 7·1; N, 3·0. $C_{13}H_{19}O_4N$ requires C, 61·7; H, 7·5; N, 5·5%).

Carboxynorcaryophyllenic acid. 18 G. of the impure cyanonorcaryophyllenic ester were refluxed for 72 hours with 36 g. of potassium hydroxide in 180 c.c. of water. The product was acidified, and extracted with ether. After drying and removal of ether, the product solidified in a vacuum desiccator (10·5 g.; m. p. 163—165°). It was dissolved in 30 c.c. of water, and crystallised by saturating the solution with hydrogen chloride while cooling it in ice; yield, 6·9 g. of almost pure acid, m. p. 170—171° (decomp.). A further crystallisation by the same method yielded pure 3 : *3-dimethyl*cyclo*butane*-1 : 2 : 2(1 : 1 : 2)-*tricarboxylic acid* in prisms, m. p. 176° (decomp.) (Found: C, 49·7; H, 5·8. $C_9H_{12}O_6$ requires C, 50·0; H, 5·6%).

Norcaryophyllenic acid. (i) 9·7 G. of carboxynorcaryophyllenic acid were heated to 175—180° for 15 minutes, the evolution of carbon dioxide having then ceased. The cooled residue was taken up in water, and the solution evaporated to dryness. The resulting semi-solid mass (7·8 g.) was dissolved in 50 c.c. of hot water and made just alkaline with ammonia. An excess of 25% calcium chloride solution was added to the boiling solution, and the copious precipitate filtered off hot and washed with hot water. It was then dissolved in hydrochloric acid, and the

solution extracted with ether. Evaporation of the dried extract left 3·52 g. of crude acid, m. p. 134—139°; one crystallisation from water yielded 2·50 g. of almost pure *cis*-norcaryophyllenic acid, m. p. 147—150°. The filtrate from the calcium salt was acidified and extracted with ether. Evaporation of the dried extract yielded 3·95 g. of crude acid, m. p. 110—120°; one crystallisation from water afforded 2·14 g. of somewhat impure *trans*-norcaryophyllenic acid, m. p. 140—145°.

(ii) The bulk of the acids used in this work were obtained from the cyano-ester by the methods described previously (J., 1936, 595).

Resolution of dl-cis-*Norcaryophyllenic Acid.*—5·0 G. of *dl-cis*-norcaryophyllenic acid, m. p. 150—151°, were dissolved in 375 c.c. of hot water, and 8·55 g. of cinchonidine stirred in. The filtered solution, on standing, deposited 4·29 g. of salt as flattened needles. Systematic fractional crystallisation from water yielded finally 3·49 g. of the neutral cinchonidine salt of the *d*-acid in transparent prisms, m. p. 215° (decomp.), $[\alpha]_{5461}^{20°}$ — 138·0° (l = 2; c = 0·8772 in ethyl alcohol). This was dissolved in 350 c.c. of hot water containing a little alcohol and decomposed with ammonia. The precipitated cinchonidine was filtered off, and the acidified filtrate extracted with ether. Evaporation of the dried extract yielded 1·07 g. of active acid, m. p. 160—162°. Crystallisation from water (in which the active acid was less soluble than the *dl*-acid) yielded d-cis-*norcaryophyllenic acid* in plates, m. p. 163—165°, $[\alpha]_{5461}^{20°}$ + 4·9° (l = 2; c = 1·8496 in chloroform) (Found: C, 55·6; H, 7·0. $C_8H_{12}O_4$ requires C, 55·8; H, 7·0%).

The more soluble cinchonidine salt crystallised in silky needles which were too highly coloured to allow of the determination of its rotation. Decomposition of the most soluble fraction from a long series of crystallisations yielded 1·15 g. of crude active acid, m. p. 165°. One crystallisation from water afforded l-cis-*norcaryophyllenic acid* as plates, m. p. 165°, $[\alpha]_{5461}^{20°}$ — 5·9° (l = 2; c = 1·0984 in chloroform) (Found: C, 55·9; H, 7·2%). An intimate mixture of approximately equal weights of the *d*- and the *l*-acid melted at 150°.

Resolution of dl-trans-*Norcaryophyllenic Acid.*—8·22 G. of *dl-trans*-norcaryophyllenic acid, m. p. 148—149°, were dissolved in 300 c.c. of hot water and 37·64 g. of anhydrous brucine added with stirring. The filtered solution deposited, on standing, 25·44 g. of thin, hair-like needles. Two recrystallisations from water gave 13·76 g. (29·3%) of the neutral brucine salt of the *l*-acid in silky needles, $[\alpha]_{5461}^{16·5°}$ — 81·46° (l = 2; c = 1·6992 in acetone). These were dissolved in 150 c.c. of hot water and decomposed with ammonia. The filtrate from the precipitated brucine was acidified and extracted with ether. Evaporation of the dried extract left 2·32 g. of crude active acid; three crystallisations from water (in which the active acid is more soluble than the *dl*-acid) gave 0·93 g. of l-trans-*norcaryophyllenic acid* in transparent aggregates of prisms, m. p. 126°, $[\alpha]_{5461}^{18°}$ — 129·0° (l = 2; c = 2·0000 in chloroform) (Found: C, 56·2; H, 7·1. $C_8H_{12}O_4$ requires C, 55·8; H, 7·0%).

As with the *cis*-acid, the most soluble salts were too highly coloured to permit of the determination of rotation; decomposition of the most soluble fraction with ammonia yielded 3·54 g. of crude *l*-acid. Three crystallisations from water afforded d-trans-*norcaryophyllenic acid* in transparent aggregates of prisms, m. p. 123—125°, $[\alpha]_{5461}^{18°}$ + 122·3° (l = 2; c = 1·9960 in chloroform) (Found: C, 55·9; H, 6·9%).

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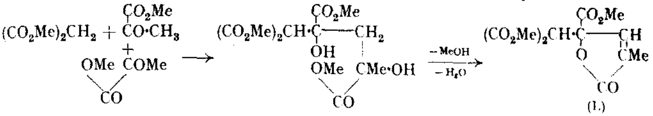
272. *Condensation of Methyl Pyruvate with Methyl Malonate in the Presence of Anhydrous Zinc Chloride.*

By John W. Baker and Annie S. Laufer.

The condensation between methyl pyruvate and methyl malonate in the presence of anhydrous zinc chloride was investigated in an attempt to effect a direct, one-stage synthesis of the ester $CO_2Me{\cdot}CMe{:}C(CO_2Me)_2$ (Baker, J., 1933, 811). The actual products of this condensation are of a more complex nature. From the neutral product was isolated a highly crystalline material, m. p. 119°, of composition $C_{12}H_{14}O_8$, which is therefore derived by condensation between 2 mols. of methyl pyruvate and 1 mol. of methyl malonate with the elimination of 1 mol. each of water and methyl alcohol. The ester is unsaturated and exhibits reducing properties. Preliminary investigation revealed the

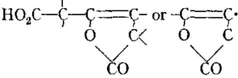
presence of three carbomethoxy-groups and a lactone ring, and suggested that it is probably a Δ^{α}-unsaturated γ-lactonic ester. Representatives of this class are not common, and a study of its reactions was considered to be of interest, especially since a closely similar system is present in the cardiac aglucones.

On the basis of the reactions recorded below, it is concluded that the substance $C_{12}H_{14}O_8$ is *methyl 2-keto-3-methyl-2 : 5-dihydrofuran-5-malonate-5-carboxylate* (I), the formation of which from the pyruvic and malonic esters can be readily represented by the scheme

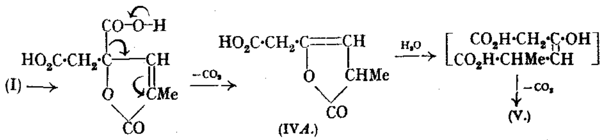


(I.)

Hydrolysis of (I) with 50% aqueous potassium hydroxide under mild conditions converts it into a *methyl dihydrogen* ester. This must possess the structure (II), the carbomethoxy-group attached to the quaternary carbon remaining unhydrolysed. It is a malonic acid, and is converted by heating at its melting point into the *methyl hydrogen* ester (III), with loss of carbon dioxide. Hydrolysis of this new ester with hot concentrated hydrochloric acid causes fission of the 5-carbomethoxy-group to give *2-keto-3-methyl-2 : 5-dihydrofuran-5-acetic acid* (IV), which, in agreement with the structure assigned, affords only a *mono-methyl* ester, b. p. 126°/1 mm., when treated with diazomethane. The same acid is obtained by direct hydrolysis of the ester (I) with concentrated hydrochloric acid, but, under these conditions, a considerable quantity of a liquid keto-acid, $C_6H_{10}O_3$ (V), is also formed. The simultaneous production of this keto-acid suggests that the hydroxyl group, introduced by the opening of the lactone ring in the lactonic acid $C_7H_8O_4$, is capable of ketonisation, to produce a β-keto-acid, which then loses a molecule of carbon dioxide to give the acid $C_6H_{10}O_3$. This hypothesis requires the presence in the precursor of the grouping

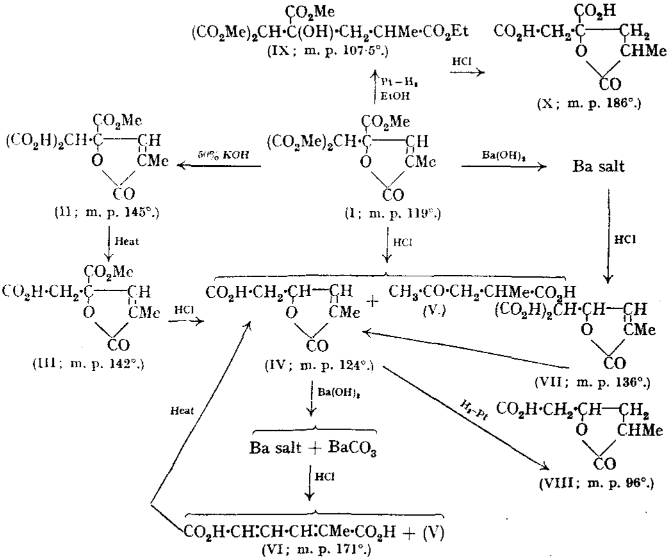


The ketonic acid $C_6H_{10}O_3$ is not a β-ketonic acid; hence the number of possible isomerides is not large. Systematic synthesis of the possible structures showed the liquid keto-acid to be identical with α-methyl-lævulic acid, obtained by acid hydrolysis of *methyl β-acetyl-α-methylsuccinate*, the condensation product from methyl α-bromopropionate and methyl sodioacetoacetate. The keto-acid is apparently derived from a 2 : 3-dihydrofuran structure (IV*A*) which, in theory, could be obtained by prototropic change from the 2 : 5-dihydro-acid (IV). In this system, however, the 2 : 5-dihydro-compound should be the favoured isomeride, since the polar effect of the 3-methyl group would be to stabilise the double bond in the αβ-position.* Actually, no trace of the keto-acid can be detected when the pure lactonic acid (IV) is heated with concentrated hydrochloric acid, and it must, therefore, be concluded that the considerable amount formed during the similar hydrolysis of the parent ester (I) is derived from the 2 : 3-dihydro-acid which results from the extrusion of carbon dioxide necessary to provide the requisite hydrogen atom for prototropic mobility in the potential three-carbon system :



* It is of interest, however, that the acid (IV) gives a positive Legal test, which Jacobs, Hoffmann, and Gustus (*J. Biol. Chem.*, 1926, **70**, 1) found to be typical of βγ-unsaturated γ-lactones having an α-hydrogen atom. In accordance with their conclusions, neither the ester (I) nor the saturated lactonic acid (VIII) gives a positive reaction.

Confirmation of this view is provided by the hydrolysis of the acid (IV) with boiling barium hydroxide solution. Precipitation of barium carbonate indicates the elimination of a carboxyl group, and back-titration shows that 2—3 equivs. of the baryta have been used. Acidification of the soluble barium salt gives an unsaturated acid (VI), isomeric with (IV), and the keto-acid $C_6H_{10}O_3$. The greater mobility of the prototropic system in the presence of the alkaline reagent evidently permits the formation of the unsaturated lactonic acid (IV*A*) from which the keto-acid is derived. Unlike its precursor, the unsaturated acid (VI) is dibasic but is reconverted into the lactonic acid (IV) when it is heated at its melting point : (VI) is therefore most probably *α-methylmuconic acid*, formed by ethylenic elimination of water from the intermediate hydroxy-acid. Its conversion into the lactonic acid



when heated is exactly comparable to the similar conversion of β-methylmuconic acid into 2-keto-4-methyl-2 : 5-dihydrofuran-5-acetic acid (Pauly and Will, *Annalen*, **1917**, **416**, 1). An attempt was made to synthesise α-methylmuconic acid by the action of concentrated alcoholic potassium hydroxide upon the product of dibromination of α-methyladipic acid. The resulting acid, m. p. 276° (decomp.), gave the correct analytical figures and is evidently the high-melting form, since it was reduced to α-methyladipic acid. The acid obtained by hydrolysis of the lactonic acid (IV) is probably the low-melting form, although with the small amount of material available no pure crystalline material could be isolated from its reduction product. Hydrolysis of the original ester (I) with boiling barium hydroxide solution gives a crystalline *barium* salt, from which is obtained *2-keto-3-methyl-2 : 5-dihydrofuran-5-malonic acid* (VII). This, in agreement with the structure assigned, is converted into the 5-acetic acid (IV) at its melting point.

Reduction of the unsaturated lactonic acid with hydrogen and a platinum-black catalyst

converts it into *2-keto-3-methyltetrahydrofuran-5-acetic acid* (VIII). Saturation of the ethylenic bond destroys the prototropic system present in (IV) and thus precludes the possibility of the formation of the open-chain keto-acid by alkaline hydrolysis. In agreement with this it was found that only 2 equivs. of baryta were neutralised in the complete hydrolysis of the dihydro-acid.

Catalytic reduction (Adams) of the original ester proceeds smoothly in alcohol, but between 3 and 4 atoms of hydrogen are absorbed. Analysis of the product, however, agrees well with the composition of a *dihydro*-derivative which has added on one molecule of ethyl alcohol. The nature of this addition is uncertain, especially since the original unsaturated derivative (I) crystallises unchanged from hot alcohol, but it is considered probable that addition has occurred with rupture of the lactone ring to give *methyl β-hydroxy-δ-carbethoxy-n-pentane-ααβ-tricarboxylate* (IX). Hydrolysis of this ester with concentrated hydrochloric acid affords the normal dihydro-derivative *2-keto-3-methyltetrahydrofuran-5-acetic-5-carboxylic acid* (X). The retention of the 5-carboxyl group in the hydrolysis of the dihydro-ester, contrasted with its elimination when the acid hydrolysis precedes the reduction (to give the acid VIII), indicates that such elimination must be associated with the presence of the unsaturated lactone structure.

Attempts to elucidate the structure of the ester (I) and its hydrolysis product (IV) by ozonolysis were only partly successful. Formaldehyde and a little oxalic acid were the only identified products when the ozonide of (I) was decomposed by cold water. Formaldehyde was also detected in the volatile products obtained by the decomposition of the ozonide of (IV) by boiling water, and the acid portion, obtained by further oxidation with perhydrol in sodium bicarbonate solution, contained formic acid. In one experiment a very small yield of an acid, m. p. 118°, was isolated. It depressed the m. p. of the original acid (IV) and of methylsuccinic acid, and there is little doubt (see p. 1348) that it was slightly impure *dl*-malic acid. The isolation of this large fragment of the carbon skeleton of (IV) is strong confirmation of the correctness of the structure assigned.

The inter-relationships of these various derivatives are summarised in the scheme on p. 1344.

EXPERIMENTAL.

Condensation of Methyl Pyruvate with Methyl Malonate.—Various methods described in the literature for the esterification of pyruvic acid were tried, but most satisfactory results were obtained by use of the alcohol-vapour method without a catalyst, care being taken, by use of an efficient column, to prevent entrainment of the ester. Fractionation of the product obtained by passage of about 2 l. of methyl alcohol into 100 g. of pyruvic acid afforded approximately 30 g. of the ester, b. p. 132—136°. Attempts to oxidise methyl lactate directly to methyl pyruvate with selenium dioxide were unsuccessful.

Methyl 2-Keto-3-methyl-2 : 5-dihydrofuran-5-malonate-5-carboxylate (I).—Although this ester is derived from 2 mols. of methyl pyruvate and 1 mol. of methyl malonate, only a small yield is obtained when the esters are used in this ratio : much improved yields are obtained by using equimolecular quantities. A mixture of 42 g. of methyl pyruvate, 39 g. of methyl malonate, and 40 g. of powdered anhydrous zinc chloride was heated on the steam-bath for 2 hours. The yellow, viscous reaction mixture was cooled, poured into water, and the neutral products isolated by ether extraction in the usual manner. The concentrated ethereal solution deposited crystals (approx. 9 g.) which, recrystallised from dilute alcohol, gave the *ester*, m. p. 119° (Found : C, 50·4, 50·5; H, 5·0, 5·0; OMe, 32·35; *M*, 260, 262, 265. $C_{12}H_{14}O_8$ requires C, 50·35; H, 4·9; 3OMe, 32·5%; *M*, 286). Hydrolysis with 0·0457*N*-baryta and back-titration of the excess gave equiv. 72·4 (Calc. for $4CO_2H$: equiv., 71·5). The ester rapidly decolorises Baeyer's reagent, and readily reduces boiling Fehling's solution and ammoniacal silver nitrate. It was recovered unchanged from attempts to condense it with piperonal, *o*-phenylenediamine, phenylcarbimide, and semicarbazide, or from interaction with diazomethane, and it would not form an acetyl derivative. Attempted methylation with methyl-alcoholic sodium methoxide and methyl iodide at atmospheric pressure afforded unchanged material as the only crystalline product. When the same reagents, with a large excess of methyl iodide, were heated in a sealed tube at 100°, the neutral product consisted of a yellow liquid which could not be induced to crystallise and was not examined further.

Repeated fractional distillation of the viscous yellow mother-liquor from which the ester

(I) had separated gave unchanged methyl malonate, and a pale yellow unsaturated liquid *ester*, b. p. 101°/0·6 mm. Analysis of this agrees with the composition $C_{14}H_{16}O_9$, but investigation of this product is only in the preliminary stages [Found: C, 50·5; H, 6·15; OMe, 37·8. $C_{10}H_8O_5(OCH_3)_4$ requires C, 50·6; H, 6·03; OMe, 37·4%].

Hydrolysis of (I).—(a) *With potassium hydroxide.* The yellow solution obtained by dissolving 2 g. of the ester in 10 c.c. of 50% aqueous hydroxide was warmed to 80° on the steam-bath for a few minutes, cooled to 0°, extracted with ether, and the aqueous mother-liquor acidified with concentrated hydrochloric acid at 0°. The residue from the dried ethereal extract crystallised. Crystallisation from dry ether containing a few drops of chloroform gave the *methyl dihydrogen* ester (II), m. p. 145° (decomp.) (Found: C, 46·5; H, 3·9; OMe, 11·85; equiv., dibasic, 129·2. $C_{10}H_{10}O_8$ requires C, 46·5; H, 3·9; OMe, 12·0%; equiv., 129). The ester was heated at 145° until gas evolution ceased, and the resulting yellow liquid was dissolved in aqueous sodium bicarbonate. After ether extraction of any non-acidic material, the acid was liberated by addition of concentrated hydrochloric acid at 0°. The residue from the dried ethereal extract crystallised from ether containing a little ligroin to give *5-carbomethoxy-2-keto-3-methyl-2 : 5-dihydrofuran-5-acetic acid* (III), m. p. 144°, depressed to 120—125° by admixture with the ester (II) (Found: C, 50·5; H, 4·8; OMe, 14·6; equiv., monobasic, *ca.* 195.* $C_9H_{10}O_6$ requires C, 50·5; H, 4·7; OMe, 14·5%; equiv., 214).

(b) *With barium hydroxide.* 2 G. of the ester (I) were gently refluxed with 750 c.c. of approx. 0·05*N*-baryta for 1 hour, with exclusion of carbon dioxide. The precipitated *barium* salt was filtered from the hot solution and washed successively with water, alcohol, and ether (Found: Ba, 44·9; H_2O, loss at 150°/5 mm., 7·0. $C_{16}H_{14}O_{14}Ba_3,4H_2O$ requires Ba, 45·1; H_2O, 7·8%). The barium salt was added, with constant shaking, to concentrated hydrochloric acid at 0°, and the liberated acid was extracted with ether. The residue from the dried extract slowly crystallised. Crystallisation from ether–ligroin (b. p. 60—80°) gave *2-keto-3-methyl-2 : 5-dihydrofuran-5-malonic acid* (VII), m. p. 136° (decomp.) (Found: C, 48·3; H, 4·1; equiv., by direct titration, 100·2; equiv., by back titration, 64·0. $C_8H_8O_6$ requires C, 48·0; H, 4·0%; equiv., 100·0 and 66·6, respectively). When heated at 135—140° until gas evolution had ceased, this acid was converted into the 5-acetic acid (IV), m. p. and mixed m. p. 124°.

(c) *With concentrated hydrochloric acid.* The original ester (I) (5 g.) was heated on a steam-bath with 30 c.c. of concentrated hydrochloric acid until evolution of carbon dioxide had ceased (1—1·5 hours). The hydrochloric acid was evaporated on the steam-bath, and the residue evaporated several times with ether until a homogeneous solution in ether was obtained. After concentration, crystals of *2-keto-3-methyl-2 : 5-dihydrofuran-5-acetic acid* (IV) separated. After crystallisation from ether, the acid had m. p. 124° (Found: C, 54·25, 54·2, 54·2; H, 5·4, 5·2, 5·2; equiv., 157·2. $C_7H_8O_4$ requires C, 53·9; H, 5·1%; equiv., monobasic, 156). The acid was converted by diazomethane in ether–chloroform solution into its *methyl* ester, b. p. 126°/1 mm. (Found: C, 56·3; H, 6·2; OMe, 18·9. $C_8H_{10}O_4$ requires C, 56·5; H, 5·9; OMe, 18·2%).

Evaporation of the ethereal mother-liquor from which the lactonic acid had separated afforded a pale yellow syrup which was essentially α-methyl-lævulic acid. It was characterised as its semicarbazone, m. p. 182° (decomp.) (Found: C, 45·3; H, 7·0; N, 22·3. Calc. for $C_7H_{13}O_3N_3$: C, 44·9; H, 7·0; N, 22·4%), and its p-*nitrophenylhydrazone*, m. p. 170° (Found: C, 54·6; H, 5·6. $C_{12}H_{15}O_4N_3$ requires C, 54·35; H, 5·7%). It was converted (methyl alcohol–sulphuric acid) into its methyl ester, characterised as its p-*nitrophenylhydrazone*, m. p. 142° (Found: C, 55·9; H, 6·2. $C_{13}H_{17}O_4N_3$ requires C, 55·9; H, 6·1%). All these derivatives gave no depression when admixed with specimens obtained from synthetic α-methyl-lævulic acid (below).

Synthesis of γ-Keto-acids $C_6H_{10}O_3$.—*β-Methyl-lævulic acid.* Distillation of the neutral product obtained by the action of 20 g. of methyl iodoacetate upon the sodium compound prepared from 2·3 g. of sodium in 50 c.c. of dry methyl alcohol and 13 g. of methyl methyl-acetoacetate gave *methyl γ-keto-β-methyl-*n*-butane-αβ-dicarboxylate*, b. p. 125—126°/11 mm. (Found: C, 53·85; H, 6·9. $C_9H_{14}O_5$ requires C, 53·5; H, 7·0%). Its *semicarbazone*, m. p. 151° from dilute alcohol, only separates after the reaction mixture has been kept for several days (Found: C, 46·8; H, 6·7. $C_{10}H_{17}O_5N_3$ requires C, 46·3; H, 6·6%). Hydrolysis of this ester with concentrated hydrochloric acid on a steam-bath until gas evolution ceases affords β-methyl-lævulic acid. The semicarbazone, m. p. 179—180° (decomp.), is depressed to 167° by admixture with that of the liquid keto-acid obtained by hydrolysis of the ester (I).

* Most equivalents in this paper were determined with a few mg. of material, an ordinary analytical balance and a microburette being used, and are thus subject to an error of several units %.

α-Methyl-lævulic acid. Similar condensation of methyl acetoacetate and methyl α-bromopropionate afforded *methyl δ-keto-n-pentane-βγ-dicarboxylate*, b. p. 128·5°/12 mm. (Found : C, 54·2; H, 7·2. $C_9H_{14}O_5$ requires C, 53·5; H, 7·0%). Hydrolysis with concentrated hydrochloric acid gave α-methyl-lævulic acid as a colourless syrup, readily characterised as its semicarbazone, m. p. and mixed m. p. 181° (decomp.) [Gault and Salomon, *Ann. Chim.*, 1924, **2**, 133, give m. p. 189° (corr.), but repeated crystallisation did not raise the m. p. above 182°]. Its *p*-nitrophenylhydrazone, m. p. and mixed m. p. 170°, and the *p*-nitrophenylhydrazone of its methyl ester, m. p. and mixed m. p. 142°, were identical with the corresponding derivatives of the keto-acid obtained by hydrolysis of the ester (I).

Action of Aqueous Barium Hydroxide upon (IV).—0·048 G. of the 5-acetic acid (IV) was refluxed with 20 c.c. of 0·0457*N*-barium hydroxide. Titration of the excess with standard hydrochloric acid showed that 17·72 c.c. of the baryta had been used, corresponding to 2·63 equivs. per mol. A larger-scale experiment, after filtration of the precipitated barium carbonate (equivalent to 63% elimination of one carboxyl group), removal of the excess baryta with carbon dioxide, and evaporation to dryness, gave a barium salt (Found : Ba, 39·7%) which was added to a small quantity of moderately concentrated hydrochloric acid (1 : 1) at 0°. The concentrated, dried ethereal extract deposited crystals of *α-methylmuconic acid*, m. p. 171°, after crystallisation from acetone–chloroform (Found : C, 54·3; H, 5·55; equiv., 74·3. $C_7H_8O_4$ requires C, 53·9; H, 5·1%; equiv., dibasic, 78). The ethereal mother-liquors gave a gummy acid which readily yielded a semicarbazone, m. p. 179° (decomp.), raised to 180° by admixture with that of a synthetic specimen of α-methyl-lævulic acid. A small quantity of the α-methylmuconic acid was heated to its m. p. for a few minutes and then cooled. Crystallisation of the product first from acetone and then from ether gave an acid, m. p. 122°, raised to 124° by admixture with the 5-acetic acid (IV).

Reduction of the Lactonic Acid (IV).—The acid (0·2 g.) was shaken with hydrogen and platinum-black in alcohol under atmospheric pressure for some days, absorption being very slow. Filtration and evaporation of the solution gave the *dihydro-acid* (VIII), m. p. 96° with previous softening, after crystallisation from ether–chloroform (Found : C, 52·9; H, 6·6; equiv., by direct titration, 156·4; by back titration, 78. $C_7H_{10}O_4$ requires C, 53·0; H, 6·4%; equiv., monobasic, 158; dibasic, 79).

Reduction of the Ester (I).—The ester (1·43 g.) was suspended in about 80 c.c. of 96% alcohol and reduced with hydrogen, 0·1 g. of platinum oxide being used as catalyst. Absorption of approximately 1 mol. of hydrogen (133 c.c.) occurred during the first 6 hours, but overnight a further 80 c.c. were absorbed. The solution was warmed to dissolve all the product, filtered, concentrated to a very small bulk, and left to crystallise in the refrigerator. After draining on porous porcelain, the *ester* (IX) crystallised from ether in rosette clusters of short prisms, softening 105°, m. p. 107·5° (Found : C, 50·6; H, 6·0. $C_{14}H_{22}O_9$ requires C, 50·3; H, 6·6%. $C_{12}H_{16}O_8$ requires C, 50·0; H, 5·55%). A mixture of the reduction product and the original ester melted at 104—108°. 0·15 G. of this ester was heated with 5 c.c. of concentrated hydrochloric acid for 2 hours and evaporated on the steam-bath. The residue crystallised when rubbed with ether–ligroin. Crystallisation from ethyl acetate–ligroin (b. p. 60—80°) gave 2-*keto-3-methyltetrahydrofuran-5-acetic-5-carboxylic acid* (X), m. p. 186° (Found : C, 47·8; H, 5·1. $C_8H_{10}O_6$ requires C, 47·5; H, 4·95%).

Ozonolysis of the Ester (I).—The solution resulting from the passage of ozonised oxygen through a solution of approximately 1 g. of the ester in chloroform at 0° for 24 hours was evaporated in a vacuum at room temperature, and the syrupy residue decomposed by shaking with cold water for 48 hours. A small amount of crystalline material, m. p. approx. 115°, remained undissolved, but was converted into a gum when crystallisation from dilute alcohol was attempted. Distillation of a portion of the aqueous solution gave some formaldehyde, identified as its dimedon compound, m. p. and mixed m. p. 189—190°. The presence of oxalic acid was demonstrated in the usual manner in the residual aqueous liquor. No crystalline or identifiable products were obtained from the ethereal extract of the aqueous liquor.

Ozonolysis of the Acid (IV).—Similar ozonolysis of this acid gave an insoluble, partly crystalline ozonide which was decomposed by boiling with water. The volatile products, passed into a solution of *p*-nitrophenylhydrazone in dilute hydrochloric acid, gave a small amount of a reddish precipitate, decomp. 260—265°. Formaldehyde was also detected as its dimedon compound in the aqueous distillate. The residual aqueous liquor was oxidised with sodium bicarbonate and perhydrol at room temperature for several days, and the neutral and acid fractions isolated with ether in the usual manner. The former gave only a trace of crystalline material too small for investigation, whilst the acid residue had the strong odour of formic acid and reduced

ammoniacal silver nitrate and acid permanganate. The aqueous acidified mother-liquor was evaporated to dryness on a steam-bath, and the residue repeatedly extracted with dry acetone. The residue from the evaporated extract was unsaturated towards Baeyer's reagent and, after crystallisation from ether–ligroin, had m. p. 118°, depressed to 105° by the original acid (IV), and to 100—104° by admixture with methylsuccinic acid. The mixture with *dl*-malic acid, m. p. 134°, softened at 128° and had m. p. 134° (Found, in sample dried at room temp. in a vacuum: C,35·0; H, 4·3. Calc. for $C_4H_6O_5$: C, 35·8; H, 4·5%).

Synthesis of α-Methylmuconic Acid.—α-Methyladipic acid (1·2 g. prepared by alkaline hydrolysis of ethyl 2-methyl*cyclo*pentanone-2-carboxylate) and 6·5 g. of phosphorus pentabromide were warmed together on a steam-bath until the action was complete; 2·4 g. of dry bromine were added, and the mixture was heated on the steam-bath in the direct light of a 100-watt lamp for 18 hours. The product was refluxed with ligroin at 40—60°, evaporated, and, when cold, was poured dropwise into a solution of 20 g. of potassium hydroxide in 40 c.c. of 96% alcohol at 0°. The alkaline solution was gently refluxed for one hour, cooled to 0°, and non-acidic material extracted with ether. The aqueous liquor was added to ice-cold concentrated hydrochloric acid, extracted with ether, and the dried ethereal solution concentrated to small bulk. *α-Methylmuconic acid*, m. p. 276° (decomp.), separated (Found: C, 54·1; H, 5·2. $C_7H_8O_4$ requires C, 53·9; H, 5·1%). This acid was highly unsaturated and was rapidly reduced by hydrogen and platinum-black in aqueous alcohol. Isolation of the product in the usual manner gave α-methyladipic acid, m. p. and mixed m. p. 59°.

THE UNIVERSITY, LEEDS. [*Received, June 7th,* 1937.]

273. *Derivatives of* o-*Hydroxybenzylsulphonic Acid.*

By EDWIN A. SHEARING and SAMUEL SMILES.

For further study of the alkali derivatives of di-2-hydroxynaphthyl-1-methane we required the unsymmetrical derivatives of the latter, and the experiments now described were undertaken with the object of synthesising these. A suitable process has been found in the reaction between 2-naphthol and its 1-methanesulphonate which is shown to be reversible. Sodium 2-hydroxybenzylsulphonate and its nuclear homologues may be obtained (1) from the relevant phenol with formaldehyde and sodium sulphite, (2) from the 2-hydroxybenzyl alcohol and sodium bisulphite, but the reactivities of these products with 2-naphthol are in general less than that of 2-hydroxynaphthyl-1-methanesulphonate. An interpretation of the notably high activity of R in $C_{10}H_6OH{\cdot}CH_2R$ is offered and this has led to the observation that 2-hydroxynaphthyl-1-thiolsulphonate is readily formed from sodium sulphite and di-2-hydroxynaphthyl 1-sulphide.

FURTHER study of the covalent alkali derivatives of di-2-hydroxynaphthyl-1-methane and di-2-hydroxynaphthyl 1-sulphide required unsymmetrical derivatives of these types; methods of synthesising these from the chloro-thiols are available in the sulphide series (J., 1930, 1741) but not in the methane series. The experiments now recorded were undertaken in order to render the unsymmetrical derivatives of the latter group available. There is no doubt that reaction of 2-naphthol or its derivatives with 2-hydroxynaphthyl-1-methanol would lead to the desired result, but the latter substance is not easily available (Betti and Mundici, *Gazzetta*, 1906, **36**, 660; Shoesmith and Rubli, J., 1927, 3101) whilst the 1-chloromethyl derivative is unknown. According to patent literature (D.R.P. 87,335) sodium 2-naphthol-1-methanesulphonate is formed by heating an aqueous solution of formaldehyde and sodium sulphite with 2-naphthol. Very little is known of the sequence of reactions taking place in this process, but it may be noted that Cohen and Clutterbuck (J., 1923, **123**, 2510), having isolated 2-hydroxynaphthyl-1-methanol as a subsidiary product, were inclined to regard the formation of sulphonate as taking place as follows:

$$C_{10}H_7OH \longrightarrow C_{10}H_6(OH){\cdot}CH_2{\cdot}OH \xrightarrow{Na_2SO_3} C_{10}H_6(OH){\cdot}CH_2{\cdot}SO_3Na + NaOH$$

In the present experiments, however, the occurrence of this alcohol among the products has been confirmed. Instead, di-2-hydroxynaphthyl-1-methane has always been met with;

in fact, a relatively large amount of this substance, evidently arising from the condensation of 2-naphthol with formaldehyde (Manasse, *Ber.*, 1894, **27**, 2412), is liberated at an early stage but this diminishes as the reaction proceeds. Further experiment has established the fact that di-2-hydroxynaphthyl-1-methane is resolved by hot aqueous sodium sulphite into sodium 2-naphthoxide and sodium 2-naphthol-1-methanesulphonate (I, *a*); moreover, the process is reversible, the methane derivative being readily formed from the sulphonate with excess of naphthoxide (I, *b*).

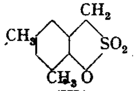
$$\text{(I.)}\quad (C_{10}H_6{\cdot}OH)_2CH_2 + Na_2SO_3 \underset{b}{\overset{a}{\rightleftharpoons}} C_{10}H_6(OH){\cdot}CH_2{\cdot}SO_3Na + C_{10}H_7{\cdot}ONa$$

Not all derivatives of di-2-hydroxynaphthyl-1-methane are so easily resolved by sulphite as the parent substance; for example, the 6 : 6′-dibromo-derivative remains almost unattacked under the same conditions, and the unsubstituted monomethyl ether behaves similarly. Nevertheless, when 6-bromo-2-naphthol is used instead of 2-naphthol in the reaction with sulphite and formaldehyde, satisfactory yields of 6-bromo-2-naphthol-1-methanesulphonate are obtained together with *bis-(6-bromo-2-hydroxynaphthyl)-1-methane*. For these reasons it is concluded that in the original process the source of 2-naphthol-1-methanesulphonate is at least twofold: fission of the methane (I, *a*) and condensation of sodium 2-naphthoxide with formaldehydebisulphite (II).

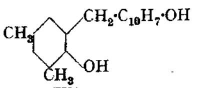
$$\text{(II.)}\quad C_{10}H_7{\cdot}ONa + CH_2(OH)(SO_3Na) \longrightarrow H_2O + C_{10}H_6(ONa)(CH_2{\cdot}SO_3Na)$$

Support for the process indicated by Cohen and Clutterbuck has not been found by isolation of the methanol, but since the conversion of this into the sulphonate by sodium sulphite is without doubt attainable, their suggested process may be regarded as a third possible source of the product.

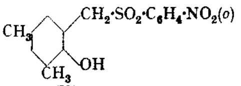
The process I, *b* may conveniently be used for the synthesis of unsymmetrically substituted di-2-hydroxynaphthyl-1-methanes; the method is illustrated by the cases of the 3-*bromo*- and 6-*bromo*-derivatives. With the object of widening the application of this process, other means of obtaining *o*-hydroxymethanesulphonates were sought. It is now shown that these may be obtained by the interaction of sodium bisulphite and 2-hydroxybenzyl alcohol or its nuclear homologues, as well as by the reaction of formaldehyde and sodium sulphite with suitable phenols. The products were characterised by conversion into the " benzylsultones " (Marckwald and Fahne, *Ber.*, 1898, **31**, 1868), *e.g.*, (III). Except in the case of the dimethyl derivative (compare III) the yields of the sulphonates under the usual conditions were relatively small and it is noteworthy that benzyl alcohol does not exhibit this behaviour. Moreover, the reactivities of these sulphonates with sodium 2-naphthoxide was poor compared with that of 2-naphthol-1-methanesulphonate, (IV), for example, being obtained only in small yield. This *substance*, however, may be obtained in good yield by the interaction of 2-naphthol and 5-chloromethyl-*m*-4-xylenol.



(III.)



(IV.)



(V.)

Sulphones such as (V), generated by reaction of a sulphinate with the 2-hydroxybenzyl chloride, have also been examined. Under mildly alkaline conditions these substances suffer fission at the $-CH_2{\cdot}SO_2-$ group, the sulphinate being regenerated; in fact, the sulphone (V) did not undergo the intramolecular displacement characteristic of the homologous 2′-nitro-2-hydroxydiphenylsulphones (J., 1934, 422).

On reviewing the facts now recorded, together with others such as the fission of di-2-hydroxynaphthyl-1-methane by alkaline reduction (Fries and Hubner, *Ber.*, 1906, **39**, 435), it is evident that the group R in $HO{\cdot}C_{10}H_6{\cdot}CH_2R$ possesses exceptionally high mobility. This circumstance is adequately explained by the work of Baddeley and Bennett (J., 1933, 263), who have shown that the hydrolysis of substituted benzyl chlorides is favoured by

electron accession at the methane carbon atom. In the present case this electron accession is evidently due to the *o*-phenolic ion and is further increased by attachment of the methane carbon atom to the 1-position in the 2-naphthol nucleus. Finally, it may be observed that according to these views a similar behaviour must be expected of di-2-hydroxynaphthyl 1-sulphide. Facts fulfilling this requirement are forthcoming; *e.g.*, the sulphide in alkaline media may assume the keto-hydroxy-condition (J., 1930, 959), it is converted by alkaline reduction into 2-naphthol and 2-hydroxy-1-thiolnaphthalene, whilst it is now shown that like the methane derivative (I, *a*) it is resolved by sodium sulphite into 2-naphthol and the *thiolsulphonate* $C_{10}H_6(OH)(S{\cdot}SO_3Na)$.

EXPERIMENTAL.

Di-2-hydroxynaphthyl-1-methane.—Formaldehyde (19 g.; 40%) was added to a solution of sodium sulphite (63 g.) in water (250 c.c.) containing 2-naphthol (36 g.) in suspension. This was heated (10 mins., 100°) and the crystalline material (15 g.) which had separated was identified as di-2-hydroxynaphthyl-1-methane by its m. p. (199°) and by conversion into the acetyl derivative, m. p. 214° (Manasse, *loc. cit.*, gives m. p. 214°). In a duplicate experiment the di-2-hydroxy-naphthol-1-methane almost entirely dissolved after continued heating (3 hrs.).

An aqueous solution of sodium hydroxide (50 c.c., 4%) containing 2-naphthol (3·6 g.) and sodium 2-hydroxynaphthyl-1-methanesulphonate (6·5 g.) was boiled (6 hrs.). The insoluble material obtained by acidifying the cooled mixture with acetic acid yielded di-2-hydroxy-naphthyl-1-methane (3·6 g.).

Reaction with sodium sulphite. An aqueous solution of sodium hydroxide (40 c.c., 2%) containing sodium sulphite (5 g.) and di-2-hydroxynaphthyl-1-methane (6 g.) was boiled (3 hrs.). Acidification of the cooled mixture yielded the methane (2·2 g.) and 2-naphthol (1·6 g.), the sulphonate remaining in the aqueous liquor.

Sodium 6-bromo-2-hydroxynaphthyl-1-methanesulphonate. Formaldehyde (2·3 c.c., 40%) was added to a suspension of 6-bromo-2-naphthol (6·7 g.) in an aqueous solution of sodium sulphite (30 g.). The crystalline precipitate had not dissolved after the mixture had been heated for 6 hrs.; purified from amyl alcohol, it had m. p. 240° and was identical with a sample of *bis-(6-bromo-2-hydroxynaphthyl-1)-methane* which had been obtained by the method of Fries (*Ber.*, 1906, **39**, 439) from formaldehyde and 6-bromo-2-naphthol in presence of sodium acetate (Found: C, 54·9; H, 3·3. $C_{21}H_{14}O_2Br_2$ requires C, 55·0; H, 3·1%). The aqueous portion of the reacting mixture on acidification with dilute sulphuric acid yielded the desired sodium sulphonate (5 g.), which separated from hot water in plates. The *lead* salt of the *O*-methyl derivative was sparingly soluble in water [Found: C, 31·9; H, 2·7. $(C_{12}H_{10}O_4BrS)_2Pb,2H_2O$ requires C, 31·8; H, 2·6%].

6-Bromodi-2-hydroxynaphthyl-1-methane.—(*a*) An aqueous solution of *N*-sodium hydroxide (40 c.c.) containing 2-naphthol (3 g.) and sodium 6-bromo-2-hydroxynaphthyl-1-methanesulphon-ate from the foregoing preparation was boiled (6 hrs.), the crystalline material which separated being collected at intervals (1·5 g.). This separated from aqueous alcohol in prisms, m. p. 210° (decomp.) (Found: C, 66·5; H, 4·0. $C_{21}H_{15}O_2Br$ requires C, 66·6; H, 4·0%). (*b*) It was also obtained by boiling the aqueous alkaline solution (*N*/3-NaOH) of 6-bromo-2-naphthol and sodium 2-hydroxynaphthyl-1-methanesulphonate, the product which separated being collected at intervals.

3-Bromodi-2-hydroxynaphthyl-1-methane separated from the boiling solution of 3-bromo-2-naphthol and 2-hydroxynaphthyl-1-methanesulphonate in aqueous *N*/3-sodium hydroxide and was removed from time to time during the course of the reaction (5 hrs.). Purified from alcohol, it had m. p. 200° (decomp.) (Found: C, 66·3; H, 4·1. $C_{21}H_{15}O_2Br$ requires C, 66·6; H, 4·0%).

Sodium 2-Hydroxyphenylmethanesulphonate.—An aqueous solution (150 c.c.) of saligenin (8·2 g.) and sodium bisulphite (7 g.) was boiled (3 hrs.). The cold neutralised solution was evaporated, the residue being extracted with hot alcohol. Further purification of the soluble product yielded the required *sulphonate* in the crystalline state (4·5 g.) (Found: Na, 10·9. $C_7H_7O_4SNa$ requires Na, 10·7%). Further identification was effected by reaction with excess of phosphorus pentachloride, first at 20° and finally at 100° (1 hr.). After admixture with ice, an ethereal extract was obtained, which was kept in presence of sodium bicarbonate and then dried. The crude material remaining after evaporation of the solvent was sublimed in a vacuum. Benzylsultone (*loc. cit.*) was thus obtained, m. p. 86° (Found: C, 49·4; H, 3·5. Calc.: C, 49·6; H, 3·5%).

Sodium *p*-cresol-3-methanesulphonate was obtained (*a*) by reaction of aqueous sodium bisulphite with *p*-cresol-3-methanol (Manasse, *Ber.*, 1894, **27**, 2409) as described in the case of saligenin, or (*b*) by boiling (3 hrs.) an aqueous solution (100 c.c.) containing *p*-cresol (10·8 g.), sodium sulphite (37 g.), and formaldehyde (7·5 g., 40%). The neutralised solution was evaporated, the residue being treated with hot alcohol, which removed the required sulphonate (7 g.). The products from both sources were identified by conversion into the " sultone " by the usual process. 5-*Methylbenzylsultone* formed long needles, m. p. 91·5° (Found: C, 52·0; H, 4·4. $C_8H_8O_3S$ requires C, 52·2; H, 4·3%).

Sodium m-4-*Xylenol*-5-*methanesulphonate*.—(*a*) From the interaction of *m*-4-xylenol (12 g.), sodium sulphite (24 g.), and formaldehyde (8 c.c.) in boiling aqueous solution (150 c.c.), the product (14 g.) separated from the concentrated and acidified solution. (*b*) *m*-4-Xylenol-5-methanol, prepared according to Manasse (*loc. cit.*), was conveniently purified by means of the calcium chloride additive compound, which separated when an ethereal solution of the impure material was kept with finely divided fused calcium chloride. Treatment of this additive product with water readily gave the pure methanol, which was converted into the sulphonate by a boiling aqueous solution of sodium bisulphite under the usual conditions. The sulphonate was identified by conversion into 5 : 7-*dimethylbenzylsultone* by the method previously described. This sublimed in long needles, m. p. 92·5° (Found: C, 55·0; H, 5·0; S, 16·2. $C_9H_{10}O_3S$ requires C, 54·6; H, 5·0; S, 16·2%).

Sodium p-2-*Xylenol*-5-*methanesulphonate*.—*p*-2-Xylenol-4-methanol (10 g.) slowly dissolved (5 hrs.) in a boiling solution of sodium bisulphite (28 g.). After the solvent had been removed from the neutralised solution, the residue was treated with hot alcohol, from which the product (10 g.) was isolated. For analysis it was converted into the sparingly soluble *barium* salt, which separated from hot water in needles (Found: Ba, 22·6. $C_{18}H_{22}O_8S_2Ba$ requires Ba, 22·6%).

Sodium 2-*Hydroxynaphthyl*-1-*thiolsulphonate*.—After an aqueous solution (150 c.c.) of sodium sulphite (17 g.) containing di-2-hydroxynaphthyl 1-sulphide (10 g.) in suspension had been boiled (3 hrs.), it was acidified with acetic acid, and the insoluble material was extracted with warm water. The *thiolsulphonate* crystallised from the cooled aqueous extract together with some 2-naphthol, which was removed by solution in ether. Purified from hot water, the product (2·5 g.) formed plates (Found: S, 22·3; Na, 7·9. $C_{10}H_7O_4S_2Na,\frac{1}{2}H_2O$ requires S, 22·3; Na, 8·0%), which were characterised by conversion into di-2-hydroxynaphthyl 1-disulphide with warm aqueous sodium hydroxide and by its reaction with 2-naphthol. A boiling aqueous solution (25 c.c.) containing 2*N*-sodium hydroxide (3 c.c.), the thiolsulphonate (2 g.), and 2-naphthol was cooled and acidified; the insoluble material contained di-2-hydroxynaphthyl 1-sulphide (1 g.) which was identified as usual.

Derivatives of Phenylbenzylsulphone.—The following sulphones were obtained by shaking a suspension of the relevant sodium sulphinate in a benzene solution of 5-chloromethyl-*m*-4-xylenol (Fries and Kann, *Annalen*, 1907, **353**, 359). The required products were isolated from the solution and from the insoluble products of the reaction. *Phenyl*-2-*hydroxy*-3 : 5-*dimethylbenzylsulphone*, purified from acetic acid, had m. p. 87° (Found: C, 65·2; H, 5·9. $C_{15}H_{16}O_3S$ requires C, 65·2; H, 5·8%); p-*tolyl*-2-*hydroxy*-3 : 5-*dimethylbenzylsulphone*, m. p. 103° (Found: C, 66·1; H, 6·1. $C_{16}H_{18}O_3S$ requires C, 66·2; H, 6·2%), and 2′-*nitrophenyl*-2-*hydroxy*-3 : 5-*dimethylbenzylsulphone* (V), pale yellow prisms from alcohol, m. p. 168° (Found: C, 55·8; H, 5·1; S, 9·9. $C_{15}H_{15}O_5NS$ requires C, 56·0; H, 4·7; S, 10·0%). These substances readily suffered fission with aqueous alkali hydroxide, the sulphinate being liberated.

1-(2-*Hydroxy*-3 : 5-*dimethylbenzyl*)-2-*naphthol* (IV) separated (7 g.) when 2-naphthol (6 g.) and 5-chloromethyl-*m*-4-xylenol (5·7 g.) were shaken together with benzene. It was also obtained by boiling a concentrated solution of 2-naphthol and *m*-4-xylenol-5-methanol in acetic acid. It formed needles, m. p. 175° (Found: C, 81·8; H, 6·5. $C_{19}H_{18}O_2$ requires C, 82·0; H, 6·5%), from methyl alcohol. *The diacetyl* derivative, purified from methyl alcohol, had m. p. 99° (Found: C, 76·4; H, 6·2. $C_{23}H_{22}O_4$ requires C, 76·4; H, 6·1%).

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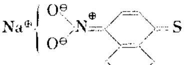
274. *The Reactions of Sodium Mono- and Di-sulphides with* 1-*Chloro*-2-*nitro*-, 2-*Chloro*-1-*nitro*-, *and* 1-*Chloro*-4-*nitro-naphthalene.*

By Herbert H. Hodgson and Eric Leigh.

The object of this work was the preparation of various dinaphthyl disulphides, but when the three chloronitronaphthalenes (1 : 2-, 2 : 1-, and 1 : 4-) reacted with sodium disulphide in a molecular ratio of 2 : 1 in boiling alcoholic solution as for the corresponding benzene analogues (Hodgson and Wilson, J., 1925, **127**, 440), mixtures of dinitrodinaphthyl mono- and di-sulphides were obtained in each case, in the proportions of about 1 : 13, 1 : 12, and 1 : 12 respectively; in contrast, the benzene compounds gave almost exclusively the disulphide. It appeared of interest, therefore, to examine the reaction with sodium mono-sulphide alone, and, under identical experimental conditions, the above proportions became about 1 : 1·2, 1 : 0·8, and 1 : 1·5 respectively, the disulphide being subsequently formed from the thiol which results initially in this reaction.

The three monosulphides were synthesised from the sodium salts of the thiols and the corresponding chloronitronaphthalenes, excellent yields being thus obtained. The sodium salts of the nitronaphthyl thiols formed red solutions in aqueous-alcoholic sodium hydroxide, a probable indication of thio-quinonoid formation (I).



(I.)

4 : 4′-Dinitro-1 : 1′-dinaphthyl disulphide has only one melting point, thereby differing from the analogous 4 : 4′-dinitro-diphenyl disulphide (Blanksma, *Rec. trav. chim.*, 1901, **20**, 141).

Hoogeveen (*ibid.*, 1931, **50**, 37) reported that 1-chloro-2-nitronaphthalene reacted with sodium disulphide to form 2 : 2′-*dinitro*-1 : 1′-*dinaphthyl disulphide*, m. p. 204°, but no analyses were given. As stated previously, this reaction afforded a mixture of monosulphide (m. p. 204°) and disulphide (m. p. 176—177°), and Hoogeveen had obviously obtained the former product by fractional crystallisation from alcohol in which the mono- is less soluble than the di-sulphide and from which it therefore separated first.

Experimental.

1-Chloro-2-nitronaphthalene was prepared by Hodgson and Walker's method (J., 1933, 824); yield 19·9 g. from 18·8 g. of 2-nitro-1-naphthylamine. It was purified by distillation in steam (volatility *ca.* 0·75 g. per l. of distillate) or in a vacuum, then crystallised twice from alcohol and once from light petroleum, being obtained in pale yellow needles, m. p. 80·5—81° (Hodgson and Kilner, J., 1926, 7, gave m. p. 76°) (Found : N, 6·9; Cl, 16·8. Calc. : N, 6·7; Cl, 17·1%).

2-Chloro-1-nitronaphthalene, prepared (yield 19·3 g. from 18·8 g. of 1-nitro-2-naphthylamine) and purified in like manner (steam volatility *ca.* 2 g. per l.), was obtained in long, almost colourless needles, m. p. 99—100° (Vésely, *Ber.*, 1905, **38**, 137, gave m. p. 95·5°; Contardi and Mor, *Rend. Ist. Lombardo*, 1924, **57**, 646, gave m. p. 98·7°) (Found : N, 6·9; Cl, 16·8%).

1-Chloro-4-nitronaphthalene, prepared (yield 19·8 g. from 18·8 g. of 4-nitro-1-naphthylamine) and purified as above (volatility in steam *ca.* 1 g. per l.), afforded fan-shaped clusters of cream, silky needles, m. p. 87—87·5° (Atterberg, *Ber.*, 1876, **9**, 927, reported bright yellow needles from alcohol, m. p. 85°) (Found : N, 6·8; Cl, 17·0%).

1-*Chloro-2-bromonaphthalene*, prepared from 1-chloro-2-naphthylamine by the ordinary Sandmeyer procedure, crystallised from alcohol in pale yellow needles and from light petroleum (b. p. 40—60°) or ligroin (b. p. 80—100°) in large, thin, pale yellow parallelepipeds, m. p. 57° (Found : Cl + Br, 48·0. $C_{10}H_6ClBr$ requires Cl + Br, 47·8%).

Reactions with Sodium Disulphide.—General procedure. Crystallised sodium sulphide (12·6 g.) and powdered sulphur (1·6 g.), dissolved in boiling alcohol (200 c.c.), were added to a boiling solution of the chloronitronaphthalene (21·3 g.) in alcohol (300 c.c.). The resulting deep red solution was heated on the water-bath for the minimum period necessary to secure complete deposition of the mixture of mono- and di-sulphide formed (*ca.* 20 mins.), cooled, filtered, and the precipitate (16·8 g. from the 1 : 2-, 14·9 g. from the 2 : 1-, and 19·5 g. from the 1 : 4-isomeride) was washed first with alcohol, then with water, and finally steam-distilled to remove traces of

unchanged chloronitronaphthalene; the filtrate above was poured into water to precipitate the remainder of the unchanged initial material, *viz.*, 2·6 g. of 1 : 2-, 3·6 g. of 2 : 1-, and 1·2 g. of 1 : 4-isomeride. It would appear from these data that the 1-chloro-4-nitro- is the most, and the 2-chloro-1-nitro-naphthalene the least reactive under the above conditions.

Separation of the mono- and di-sulphides. The mixture (5 g.) was added to a hot solution of crystalline sodium sulphide (1·75 g.) and sodium hydroxide (1·0 g.) in alcohol (150 c.c.) and water (30 c.c.), boiled for 5 minutes under reflux, and the insoluble monosulphide filtered off; the crude amounts were: 0·4 g. (m. p. 180—188°), 0·35 g. (m. p. 191—194°), and 0·4 g. (m. p. 232—235°) respectively from the 1 : 2-, 2 : 1-, and 1 : 4-isomerides. The hot, deep red filtrate above could be oxidised by air or by hydrogen peroxide, but better by addition of a hot saturated solution of potassium ferricyanide until the red colour disappeared. The crude yields of disulphide obtained were: 1·75 g. (m. p. 152—161°) from the 1 : 2-, 3·4 g. (m. p. 165—172°) from the 2 : 1-, and 4·25 g. (m. p. 178—182°) from the 1 : 4-isomeride.

Synthesis of the dinitrodinaphthyl monosulphides. The mixture of sulphide and disulphide (1·0 g.) prepared as above was added to a boiling solution of crystallised sodium sulphide (0·35 g.) and sodium hydroxide (0·2 g.) in alcohol (40 c.c.) and water (10 c.c.), refluxed for 5 minutes, filtered, and the appropriate chloronitronaphthalene (1·0 g.) dissolved in alcohol (20 c.c.) added to the filtrate. The mixture was refluxed until the red colour had disappeared (15—45 mins.) and the yellow reaction product had separated. The latter was filtered off, steam-distilled to remove unchanged chloronitronaphthalene, and crystallised from glacial acetic acid. All the three sulphides so obtained were insoluble in ether, slightly soluble in boiling alcohol but more soluble in boiling benzene, and moderately soluble in boiling glacial acetic acid and acetic anhydride. In each case the monosulphide was less soluble than the corresponding disulphide, and the 1 : 4- less soluble than the 1 : 2- and the 2 : 1-isomerides.

Action of alcoholic sodium sulphide on the chloronitronaphthalenes. Crystallised sodium sulphide (3 g.), dissolved in alcohol (25 c.c.) and water (5 c.c.), was boiled and added to a boiling solution of the chloronitronaphthalene (5·2 g.) in alcohol (50 c.c.). The resulting deep red mixture was refluxed for 10 minutes although the solid precipitate of dinitrodinaphthyl mono- and di-sulphides (as thiol) mostly separated out in about 3 minutes while the intensity of the red colour greatly diminished. After cooling, the solid matter was filtered off, washed first with hot alcohol then with water, and finally steam-distilled to remove unchanged chloronitronaphthalene. The separation of the mono- and di-sulphides was effected as above, and their ratios are reported on p. 1352.

The Individual Products.—General. The colours which each product gives with cold concentrated sulphuric acid, chlorosulphonic acid, and 26% oleum severally are placed in this order after the m. p.

1 : 1′-*Dinitro*-2 : 2′-*dinaphthyl sulphide* crystallised from hot glacial acetic acid in glistening, pale yellow, rectangular plates, m. p. and mixed m. p. with the synthetic product, 203—204° (colourless but pale violet to blue on heating; violet; violet) (Found: N, 7·5; S, 8·5 $C_{20}H_{12}O_4N_2S$ requires N, 7·4; S, 8·5%).

2 : 2′-*Dinitro*-1 : 1′-*dinaphthyl sulphide* formed pale yellow parallelepipeds, m. p. and mixed m. p. with synthetic product, 204—205° (pale yellow turning to green and then to dark blue on heating; dark greenish-brown; light brown) (Found: N, 7·5; S, 8·6%); and 4 : 4′-*dinitro*-1 : 1′-*dinaphthyl sulphide*, long golden yellow needles, m. p. and mixed m. p. with synthetic product, 239—240° (pink changing to reddish-brown; reddish-brown; dark mauve) (Found: N, 7·6; S, 8·4%).

1 : 1′-*Dinitro*-2 : 2′-*dinaphthyl disulphide* crystallised from hot glacial acetic acid (charcoal) in long, yellow parallelepipeds, m. p. 189—190° (very pale yellow which deepens on heating; deep golden-yellow; reddish-orange) (Found: N, 7·2; S, 16·0. $C_{20}H_{12}O_4N_2S_2$ requires N, 6·9; S, 15·7%).

2 : 2′-*Dinitro*-1 : 1′-*dinaphthyl disulphide* formed stout, hexagonal, yellow plates or parallelepipeds, m. p. 176—177° (yellowish-brown; brown; light brown) (Found: N, 7·1; S, 16·0%); and 4 : 4′-dinitro-1 : 1′-dinaphthyl disulphide, pale yellow needles, m. p. 188—189° (Cleve, *Ber.*, 1890, **23**, 960, gives m. p. 186°) (claret; reddish-brown; dark brown) (Found: N, 7·1; S, 15·5%).

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275. *Co-ordination Compounds of Semicarbazide, Phenylsemicarbazide,* m-*Tolylsemicarbazide, and Aminoguanidine.*

By G. STANLEY SMITH.

The objects of the investigation now described were the preparation and analysis of new complex metallic salts containing co-ordinated semicarbazide, or related compounds, with a view to determining their structure.

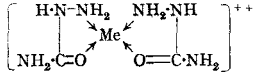
The results indicate that the organic molecule is bound to the metal atom or atoms at two points, semicarbazide giving 4- and 6-covalent nickel and cobalt, 4-covalent zinc and ferrous iron, and 2-covalent cadmium compounds; 4-phenyl- and 4-*m*-tolyl-semicarbazides giving 6-covalent nickel; and aminoguanidine giving 4-covalent nickel. 1-Phenyl- and 1-naphthyl-semicarbazides appeared not to link up with metal at all.

IN the course of experiments conducted in 1928 for a different purpose, Professor J. Kenner observed the formation of a well-defined co-ordination compound of semicarbazide with ferrous sulphate. Reference to the literature having shown that, apart from compounds with copper nitrate and copper chloride (Thiele and Stange, *Annalen*, 1894, **283**, 24), with Roussin's salt (Bellucci and Cecchetti, *Gazzetta*, 1907, **37**, i, 169), and with sodium carbonylferrocyanide (Muller, *Bull. Soc. chim.*, 1905, **33**, 947), co-ordination compounds of semicarbazide had not previously been studied, the author, at Professor Kenner's suggestion, undertook a study of their formation.

The following compounds have been isolated (sem = semicarbazide):

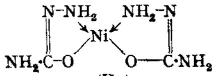
$[Fe(sem)_2]SO_4$	$[Cd(sem)]Cl_2$	$[Zn(sem)_2]SO_4$
$[Co(sem)_2]SO_4$	$[Co(sem)_2]Cl_2$	*$[Ni(sem)_2]Cl_2$
$[Ni(sem)_3]Cl_2,3H_2O$		*$[Ni(sem)_3]Cl_2$
*$[Ni(sem)_2]SO_4$	$[Ni(sem)_3]SO_4,2H_2O$	
$[Ni(sem)_3](NO_3)_2$	*$[Co(sem)_3](NO_3)_2$	$[Ni(sem)_3]ClNO_3$

All these are new except those marked with an asterisk, which have been described by Jensen and Rancke-Madsen (*Z. anorg. Chem.*, 1936, **227**, 25), who were, however, unable to isolate a compound of nickel sulphate with 3 mols. of semicarbazide. As they pointed out, the results confirm the expectation that the co-ordinative value of the semicarbazide molecule would be twice that of the ammonia or water molecule. By analogy with the

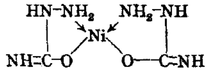
(I.) 

thiosemicarbazide complexes previously investigated by them (*ibid.*, 1934, **219**, 243; Jensen, *ibid.*, 1934, **221**, 11), the compounds would be of the type (I), in which the metal is bound both to the hydrazine group and to the oxygen atom.

Although the compounds of nickel salts with two and three molecules of semicarbazide are respectively green and blue, a pink precipitate was also observed both by Jensen and Rancke-Madsen and by the author when caustic alkali was carefully added to a concentrated solution of a nickel salt containing semicarbazide hydrochloride. The anions present in the solution do not enter into the composition of the product, which is represented



(IIa.)



(IIb.)

s
so.
dep
the p the Danish authors as an inner-complex, (II*a*) or (II*b*), the latter receiving preference
was wa similar compounds were obtained with 2-methyl- and 1 : 2-dimethyl-semicarbazides.

A compound of this composition would contain Ni, 28·37; N, 40·64%, whereas analysis gave Ni, 26·80; N, 40·41%. The discrepancy in the nickel figures was explained on the assumption that a compound containing more than 2 mols. of semicarbazide was co-precipitated. The precipitate appears as a powder when obtained in the manner described, but by slow precipitation from an alkaline tartrate solution it is obtained in crystalline form. Analysis appears to indicate that it is a complex oxide, $Ni(sem)_2O$. The compound is basic, for not only can it be titrated with acid (*Z. anorg. Chem.*, 1936, **227**, 27), but it liberates ammonia from ammonium salts. No evidence of the formation of a carbonate has been obtained. The compound is insoluble in all the common organic solvents, a fact that is not so easily explained if the complex is formulated as an "inner-complex" compound of nickel. It is precipitated also by free guanidine but not by sodium carbonate, and it can be obtained from hydrazine sulphate and potassium cyanate, without the intermediate isolation of semicarbazide. (Phillips and Williams, *J. Amer. Chem. Soc.*, 1928, **50**, 2465, obtained a complex nickel oxide with nitroaminoguanidine, $NiO[NH:C(NH{\cdot}NO_2){\cdot}NH{\cdot}NH_2]_2$, as a fawn-coloured precipitate, though this compound is soluble in sodium hydroxide.)

In view of the interest attaching to the configuration of 4-covalent compounds (cf. *Ann. Reports*, 1935, **32**, 160; 1936, **33**, 158), attempts were made to prepare tartrates of the various 4-covalent types now described, but only viscous masses could be obtained.

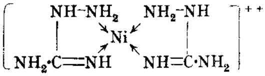
The opportunity has also been taken to study the co-ordinative behaviour of certain compounds related to semicarbazide. Thus, 4-phenylsemicarbazide (phsem) has yielded the compounds:

$[Fe(phsem)_2]SO_4$	$[Ni(phsem)_3]SO_4$	$[Ni(phsem)_3]Cl_2$
$[Ni(phsem)_3](NO_3)_2$	$[Cd(phsem)_2]Cl_2$	$[Co(phsem)_3]Cl_2$

of which only that from nickel nitrate was described by Jensen and Rancke-Madsen.

4-*m*-Tolylsemicarbazide yielded *compounds* analogous to these with cadmium chloride and nickel nitrate. On the other hand, 1-phenyl-, 1-α- and 1-β-naphthyl-semicarbazides did not participate in complex formation, and semioxamazide and oxalic dihydrazide both gave blue, amorphous compounds with nickel salts. [With alkali, the latter compounds give red or orange precipitates containing the alkali metal as well as nickel (Hofmann and Ehrhardt, *Ber.*, 1913, **46**, 1461).]

Aminoguanidine combines with nickel salts to give red salts of the type $[Ni(CH_6N_4)_2]X_2$. By analogy with the red nickel salts of 4-phenylselenosemicarbazide (Jensen and Frederiksen, *Z. anorg. Chem.*, 1936, **230**, 31), they may be formulated as:



The *chloride* and the *nitrate* of this complex are slightly soluble in water, giving red solutions, but the sulphate is practically insoluble. They are decomposed on boiling with water, nickel hydroxide being precipitated.

EXPERIMENTAL.

Free Semicarbazide.—In order to obtain several of the semicarbazide complexes it was necessary to employ the free base. This was prepared in small quantities as required by evaporating to dryness on a water-bath a concentrated solution of the hydrochloride, neutralised with potassium hydroxide, followed by extraction with hot absolute alcohol. Crystals of semicarbazide separated as the solution cooled.

Analysis.—All nitrogen data were determined by the Dumas method. Semicarbazide and aminoguanidine were determined by addition of excess potassium iodate and titration of the excess with thiosulphate (see this vol., p. 1325).

Disemicarbazidoferrous Sulphate.—2·8 G. of crystalline ferrous sulphate and 2·5 g. of semicarbazide hydrochloride were dissolved in the minimum of warm water, and a concentrated solution of 3·5 g. of crystalline sodium acetate added. Crystals formed almost at once on scratching the sides of the vessel with a glass rod, but larger crystals were obtained when the solution was

left for several hours. The *compound* could be recrystallised from hot water containing an excess of free semicarbazide. It forms white, compact crystals, moderately soluble in water, giving a solution which rapidly oxidises with the separation of ferric hydroxide. The crystals showed no signs of oxidation or decomposition in the air during several years [Found: N, 28·0; Fe, 18·5; SO_4, 31·9. $(CH_5ON_3)_2,FeSO_4$ requires N, 27·8; Fe, 18·5; SO_4, 31·8%].

Semicarbazidocadmium Chloride.—4 G. of $CdCl_2,2\frac{1}{2}H_2O$, 2·5 g. of semicarbazide hydrochloride, and 3·5 g. of sodium acetate were dissolved in nearly boiling water, and the solution allowed to cool slowly. Long, white prisms separated, which were moderately soluble in water. From fairly concentrated solutions stout crystals, over 1″ long, were often obtained when the volume of the solution was as small as 5 ml. (Found: N, 16·3; Cl, 27·3; Cd, 43·4; CH_5ON_3, 28·9. $CH_5ON_3,CdCl_2$ requires N, 16·3; Cl, 27·45; Cd, 43·5; CH_5ON_3, 29·05%). The same *compound* was obtained when the proportions of cadmium chloride and semicarbazide were varied considerably.

Disemicarbazidozinc Sulphate.—The theoretical quantities of zinc sulphate, semicarbazide hydrochloride, and sodium acetate were dissolved in hot water and the solution allowed to cool slowly. Small white crystals separated, sparingly soluble in water and in dilute sulphuric acid [Found: N, 27·0; Zn, 21·0; SO_4, 30·5; CH_5ON_3, 48·2. $(CH_5ON_3)_2,ZnSO_4$ requires N, 27·0; Zn, 21·0; SO_4, 30·8; CH_5ON_3, 48·2%].

Disemicarbazidocobalt Sulphate.—Prepared like the zinc sulphate compound, this formed small pink crystals, sparingly soluble in water [Found: N, 27·6; Co, 19·3; CH_5ON_3, 48·0. $(CH_5ON_3)_2,CoSO_4$ requires N, 27·55; Co, 19·3; CH_5ON_3, 49·2%].

Disemicarbazidocobalt Chloride.—The theoretical quantities of cobalt chloride, semicarbazide hydrochloride, and sodium acetate, dissolved in the minimum amount of hot water, gave a red solution, from which small red crystals, moderately soluble in water, separated on cooling [Found: N, 30·1; Co, 20·9; CH_5ON_3, 52·6. $(CH_5ON_3)_2,CoCl_2$ requires N, 30·0; Co, 21·1; CH_5ON_3, 53·6%].

Disemicarbazidonickel Chloride.—2·4 G. of hydrated nickel chloride and 1·4 g. of free semicarbazide were dissolved in a few ml. of water, and the bluish-green solution left on a water-bath for about ½ hour, and then cooled; 2—3 vols. of alcohol were added, and the small green crystals were filtered off, washed with alcohol, and dried in the air. The compound is moderately soluble in water [Found: N, 29·9; Cl, 25·9; Ni, 21·1; CH_5ON_3, 53·4. Calc. for $(CH_5ON_3)_2,NiCl_2$: N, 30·05; Cl, 25·35; Ni, 21·0; CH_5ON_3, 53·7%].

Trisemicarbazidonickel Chloride Trihydrate.—To 1·5 g. of free semicarbazide, dissolved in a few drops of water, a very concentrated solution of 1·5 g. of nickel chloride was added. The solutions were mixed by gentle agitation and not by stirring, since touching the sides of the vessel with a glass rod causes the compound to separate in a solid mass. After the solution had stood for a short time, blue, feathery crystals filled the liquid. The compound may be recrystallised from hot water if the solution is removed from the source of heat as soon as the complex is in solution. (If heating is continued the less soluble green complex is produced.) The *trihydrate* was collected, washed with dilute alcohol, and dried in the air [Found: N, 30·8; Cl, 17·2; Ni, 14·4; H_2O, 13·1; CH_5ON_3, 55·0. $(CH_5ON_3)_3,NiCl_2,3H_2O$ requires N, 30·8; Cl, 17·3; Ni, 14·35; H_2O, 13·2; CH_5ON_3, 55·1%]. When heated at 105°, this afforded the anhydrous compound [Found: N, 35·2; Cl, 19·5; Ni, 16·2; CH_5ON_3, 62·9. Calc. for $(CH_5ON_3)_3,NiCl_2$: N, 35·5; Cl, 20·0; Ni, 16·5; CH_5ON_3, 63·5%].

Disemicarbazidonickel Sulphate.—2·8 G. of hydrated nickel sulphate and 1·4 g. of free semicarbazide were dissolved in about 5 ml. of hot water, and the solution allowed to cool slowly. Deep green crystals, adhering to the glass, separated. They were collected, washed with water, and dried in the air. The compound is difficultly soluble in hot water [Found: N, 27·8. Calc. for $(CH_5ON_3)_2,NiSO_4$: N, 27·6%].

Trisemicarbazidonickel Sulphate.—1·5 G. of free semicarbazide, dissolved in a little water, were mixed with a concentrated solution of 1·2 g. of nickel sulphate and 2 drops of glacial acetic acid. To the quite cold solution about the same volume of methyl alcohol was added all at once. Deep blue, feathery crystals separated immediately. They were collected, and washed with 50% methyl alcohol. The *dihydrate* was dried in the air [Found: N, 30·7, 30·6, 30·1; Ni, 14·0, 14·5, 14·4. $(CH_5ON_3)_3,NiSO_4,2H_2O$ requires N, 30·3; Ni, 14·1%]. It showed no appreciable loss in a vacuum desiccator over sulphuric acid, but although it lost in weight at 105°, no constant figure could be obtained. Obvious decomposition sets in at 130° and the compound slowly turns greenish-blue. The complex is easily soluble in water and may be reprecipitated by methyl alcohol. On warming the deep blue aqueous solution, a change of colour is apparent almost at once and a green precipitate of $Ni(sem)_2SO_4$ forms.

Trisemicarbazido-nickel and -cobalt Nitrates.—These compounds were prepared by adding alcohol to concentrated solutions of the metal nitrate (1 mol.) and free semicarbazide (3 mols.). The precipitates were dissolved in the minimum of hot water, and the solutions allowed to cool very slowly. Very large compact crystals, deep blue and deep red respectively, separated. The compounds are very soluble in water but practically insoluble in alcohol. The solutions appear to be unchanged on boiling [Found, for *nickel* compound: N, 38·0; Ni, 14·4; CH_5ON_3, 55·0. $(CH_5ON_3)_3,Ni(NO_3)_2$ requires N, 37·8; Ni, 14·4; CH_5ON_3, 55·2%. Found, for cobalt compound: N, 37·6. Calc. for $(CH_5ON_3)_3,Co(NO_3)_2$: N, 37·75%].

Trisemicarbazidonickel Chloronitrate.—This *compound* was obtained (1) by adding sodium acetate to a solution containing nickel nitrate and semicarbazide hydrochloride, (2) by adding sodium acetate to nickel chloride and semicarbazide nitrate, and (3) by adding free semicarbazide to a solution containing both nickel chloride and nickel nitrate. The deep blue solution is apparently unaltered on boiling. On slow crystallisation the compound forms deep blue, elongated prisms, easily soluble in water but less so than the corresponding nitrate or chloride. There is no tendency for this compound to lose one equivalent of semicarbazide [Found: N, 36·7; Ni, 15·1; Cl, 9·4; CH_5ON_3, 59·8. $(CH_5ON_3)_3,NiClNO_3$ requires N, 36·7; Ni, 15·4; Cl, 9·3; CH_5ON_3, 59·1%].

Disemicarbazidonickelous Oxide (?).—A very finely divided, but dense, pink precipitate was obtained by adding sodium hydroxide solution to an aqueous solution of a nickel salt containing excess of semicarbazide, but the composition varied (Found: N, 37·5—41·0; Ni, 24·5—27·5%). A crystalline compound was obtained by adding a hot solution (12 ml.) containing 0·6 g. of $NiCl_2,6H_2O$, 0·6 g. of tartaric acid, and 5 ml. of 5*N*-sodium hydroxide to 1 g. of semicarbazide in about 2 ml. of hot water. No immediate precipitation occurred, but overnight small, well-defined red crystals (0·4 g.) separated [Found: N, 38·0; Ni, 26·2. Calc. for $(CH_5ON_3)_2NiO$: N, 37·4; Ni, 26·1%. Calc. for $(CH_4ON_3)_2NiO$: N, 37·7; Ni, 26·3%].

4-*Phenylsemicarbazide Complexes.*—These, with the exception of the ferrous sulphate compound, were obtained as difficultly soluble crystals by adding a solution of the semicarbazide (0·75 g.) in 10—15 ml. of boiling water to a hot solution of ½ mol. of the simple metal salt. Splendid crystals formed almost at once. The compounds were collected, washed with water, and left to dry in the air. The ferrous sulphate compound was obtained as a white crystalline powder by adding a cold solution of phenylsemicarbazide in dilute acetic acid to a cold solution of ferrous sulphate.

Complex ferrous sulphate. White [Found: N, 18·4. $(C_7H_9ON_3)_2,FeSO_4$ requires N, 18·5%]. *Complex cadmium chloride.* White [Found: N, 17·6. $(C_7H_9ON_3)_2,CdCl_2$ requires N, 17·3%]. Complex nickel nitrate. Blue [Found: N, 24·2; Ni, 9·3. Calc. for $(C_7H_9ON_3)_3,Ni(NO_3)_2$: N, 24·2; Ni, 9·2%]. *Complex nickel chloride.* Blue [Found: N, 21·3; Ni, 10·1. $(C_7H_9ON_3)_3,NiCl_2$ requires N, 21·6; Ni, 10·1%]. *Complex nickel sulphate.* Blue [Found: Ni, 9·7. $(C_7H_9ON_3)_3,NiSO_4$ requires Ni, 9·6%]. *Complex cobalt chloride.* Red [Found: N, 21·2. $(C_7H_9ON_3)_3,CoCl_2$ requires N, 21·6%].

All these compounds are less soluble in water than the corresponding semicarbazide compounds.

No compound of nickel or cobalt containing only 2 mols. of phenylsemicarbazide could be obtained.

4-m-*Tolylsemicarbazide Complexes.*—4-*m*-Tolylsemicarbazide (m. p. 108° from amyl alcohol; acetone compound, m. p. 157° from aqueous alcohol and from benzene; methyl ethyl ketone compound, m. p. 112°; benzaldehyde compound, m. p. 172°) was prepared from *m*-tolylurea and hydrazine (cf. Sah, Wang, and Kao, *J. Chinese Chem. Soc.*, 1936, 187). It gave the following complexes: *cadmium chloride* [Found: N, 16·1. $(C_8H_{11}ON_3)_2,CdCl_2$ requires N, 16·4%]; *nickel nitrate* [Found: Ni, 8·5. $(C_8H_{11}ON_3)_3,Ni(NO_3)_2$ requires Ni, 8·7%].

Aminoguanidine Compounds.—A solution of aminoguanidine sulphate, neutralised with sodium acetate and mixed with solutions of nickel and cobalt salts, gave no indications, either by reason of a change in colour of the solution or of the formation of a precipitate, of the presence of a complex, but on careful addition of ammonia or of sodium hydroxide, the nickel solution yielded a heavy, crystalline, red precipitate, and the cobalt solution a jade-green, amorphous precipitate, both compounds containing the sulphate radical. The chloride and nitrate, and also the sulphate, of the nickel–aminoguanidine complex were prepared from aminoguanidine carbonate.

Aminoguanidine carbonate (2 mols.) was treated with a measured volume, in slight excess, of 5*N*-hydrochloric, nitric, or sulphuric acid. After effervescence had ceased, sodium hydroxide (5*N*), exactly equivalent to the acid previously used, was added, and the warmed solution

poured through a disc filter into a concentrated solution of nickel chloride, nitrate, or sulphate (1 mol.). The red solutions so obtained were allowed to cool slowly. Crystals of the sulphate formed at once; the chloride and nitrate crystallised less rapidly. The sulphate is practically insoluble in water, but the other salts are slightly soluble to red solutions, which appear to be stable in the cold: *Complex chloride* [Found: Cl, 25·5; Ni, 21·2; CH_6N_4, 53·0. $(CH_6N_4)_3,NiCl_2$ requires Cl, 25·5; Ni, 21·1; CH_6N_4, 53·3%]; *complex nitrate* [Found: Ni, 17·3; CH_6N_4, 44·4. $(CH_6N_4)_3.Ni(NO_3)_2$ requires Ni, 17·7; CH_6N_4, 44·8%].

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166, Wickham Chase, West Wickham, Kent. [*Received, June 4th, 1937.*]

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276. *The Reactions of Thiocarbonyl Chloride. Part V. With Compounds containing the* –NH·NH$_2$ *Group.*

By Thomas Beckett and G. Malcolm Dyson.

The interaction of thiocarbonyl chloride with alkyl- and aryl-hydrazines leads to the formation of compounds of the carbazide type $(NHR{\cdot}NH)_2CS$; but in hydrochloric acid solution a new type of compound $CS[N(NCS)R]_2$ is obtained; in the case of certain arylhydrazines this may break down to form an aryl trithiocarbimide. The acyl hydrazides such as semicarbazide, thiosemicarbazide, and semioxamazide all form compounds of the type $CS[N(NCS){\cdot}CO{\cdot}NHR]_2$, which break down on treatment with amines, forming substituted diureas. Some of the latter, notably *s*-dicarbamidothiourea and *s*-diphenyldiureidothiourea, give coloured compounds with metal ions (especially those of cobalt, copper, and mercury) and may have application as *micro-analytical reagents.*

The use of diphenylcarbazide (Cazeneuve, *Compt. rend.*, 1900, **131**, 346), dithio-oxamide (Rây, *Z. anal. Chem.*, 1929, **79**, 94), and diphenylthiocarbazone as reagents for detection and estimation of small quantities of certain metallic ions suggested an investigation of compounds containing the NH·NH·CS·NH·NH, NH·NH·CS·N=N, and similar groups. Such compounds or their precursors can be obtained by the regulated action of thiocarbonyl chloride on compounds containing the NH·NH$_2$ group.

Heller (*Annalen*, 1891, **263**, 269) obtained *s*-diphenylthiocarbazide from thiocarbonyl chloride and phenylhydrazine in ethereal solution. It is now found that phenylhydrazine hydrochloride reacts in aqueous solution with thiocarbonyl chloride to give phenylthiocarbimide and 1 : 2 : 4-*trithiocarbimidobenzene*. It is suggested that the formation of these compounds is due to the decomposition of the initial compound $CS(NPh{\cdot}NCS)_2$ (I):

$$2Ph{\cdot}NH{\cdot}NH_2 + 3CSCl_2 \longrightarrow (I) + 6HCl$$
$$(I) \longrightarrow Ph{\cdot}NCS + Ph{\cdot}N(NCS)_2 \longrightarrow C_6H_3(NCS)_2{\cdot}NH_2$$
$$C_6H_3(NCS)_2{\cdot}NH_2 + CSCl_2 \longrightarrow C_6H_3(NCS)_3 + 2HCl$$

Substituted derivatives of (I) are sufficiently stable to be isolated.

Trithiocarbimidobenzene, a member of a hitherto uninvestigated series of compounds, was identified by analysis, by conversion into thioureas of the type $C_6H_3(NH{\cdot}CS{\cdot}NHAr)_3$ with arylamines, and by formation of a *monothiourethane* $C_6H_3(NCS)_2(NH{\cdot}CS{\cdot}OEt)$ with alcohol. Comparison with 1 : 3 : 5-*trithiocarbimidobenzene* showed its orientation to be unsymmetrical.

With an acid substituent in the para-position (*e.g.*, R = NO$_2$ or Br), the initial compound, *e.g.*, $CS[N(NCS){\cdot}C_6H_4R]_2$, is more stable and was isolated, but the reaction proceeds wholly in this direction only when the concentration of hydrogen chloride approaches 10%. In neutral solution, *p*-bromo-, *p*-nitro-, and 2 : 4-dinitro-phenylhydrazine hydrochlorides yield the corresponding symmetrical thiocarbazides.

Thiocarbonyl chloride reacts with *as*-diphenylhydrazine giving N-*thiocarbimidodiphenylamine*, which, although giving normal analytical data and molecular weight, could not be

induced to yield 1 : 1 : 4-triphenylthiosemicarbazide with aniline as might have been expected : $NPh_2{\cdot}NCS + NH_2Ph \longrightarrow NPh_2{\cdot}NH{\cdot}CS{\cdot}NHPh$.

Thiocarbonyl chloride with considerable excess of semicarbazide gives s-*dicarbamidothiourea*, $CS(NH{\cdot}NH{\cdot}CO{\cdot}NH_2)_2$, but semicarbazide hydrochloride and an excess of thiocarbonyl chloride react to give 3 : 5-*dithiocarbimidothiocarbonyldiurea* (II), the

$$2NH_2{\cdot}CO{\cdot}NH{\cdot}NH_2 + 3CSCl_2 = \underset{\text{(II.)}}{CS[N(NCS){\cdot}CO{\cdot}NH_2]_2} + 6HCl$$

structure of which was established by comparison with the analogous *compound* $CS[N(NCS){\cdot}CO{\cdot}NPh_2]_2$ from 4 : 4-diphenylsemicarbazide, where there is no structural ambiguity.

The compounds from semicarbazide and 4 : 4-diphenylsemicarbazide reacted with arylamines as follows, all the resulting compounds being identified.

(*a*) $CS[N(NCS){\cdot}CO{\cdot}NH_2]_2 + 4R{\cdot}NH_2 = 2NH_2{\cdot}CO{\cdot}NH{\cdot}NH{\cdot}CS{\cdot}NHR + CS(NHR)_2$

(*b*) $CS[N(NCS){\cdot}CO{\cdot}NPh_2]_2 + 2R{\cdot}NH_2 = \underset{\text{(III.)}}{CS[N(CO{\cdot}NPh_2){\cdot}NH{\cdot}CS{\cdot}NHR]_2}$

Further characterisation of (II) was obtained through its reaction with alcohol to give the *bisthiourethane* $CS[N(CO{\cdot}NH_2){\cdot}NH{\cdot}CS{\cdot}OEt]_2$, which reacted with arylamines thus :

(*c*) $CS[N(CO{\cdot}NH_2){\cdot}NH{\cdot}CS{\cdot}OEt]_2 + 4R{\cdot}NH_2 = 2Et{\cdot}OH +$
$2NH_2{\cdot}CO{\cdot}NH{\cdot}NH{\cdot}CS{\cdot}NHR + CS(NHR)_2$

the product being identical with that of reaction (*a*).

Thiosemicarbazide reacts similarly with thiocarbonyl chloride to give 3 : 5-*dithiocarbimidothiocarbonyldithiourea* (IV), characterised by conversion into the thiourethane $CS[N(CS{\cdot}NH_2){\cdot}NH{\cdot}CS{\cdot}OEt]_2$. With arylamines, it gives dithiourazole and thiocarbanilide.

$$\underset{\text{(IV.)}}{CS[N(NCS){\cdot}CS{\cdot}NH_2]_2} + 2R{\cdot}NH_2 = 2\begin{array}{l}NH{\cdot}NH\\ |\\ CS{-}NH\end{array}\!\!\!>\!CS + CS(NHR)_2$$

The reaction of semioxamazide with thiocarbonyl chloride runs parallel with that of semicarbazide, giving NN′-*dithiocarbimido*-NN′-*dioxamylthiourea*, $CS[N(NCS){\cdot}CO{\cdot}CO{\cdot}NH_2]_2$, the reactions of which are similar to those of (II).

Methylhydrazine and thiocarbonyl chloride interact, giving NN′-*dithiocarbimidodimethylthiourea* (V). With aromatic amines, this reacts thus :

$$\underset{\text{(V.)}}{CS(NMe{\cdot}NCS)_2} + 4R{\cdot}NH_2 = 2NHMe{\cdot}NH{\cdot}CS{\cdot}NHR + CS(NHR)_2$$

Stolle and Bowles, by interaction of thiocarbonyl chloride and hydrazine hydrate, obtained thiocarbohydrazide, $CS(NH{\cdot}NH_2)_2$. When the hydrate is replaced by a salt, such as the hydrochloride or sulphate, a new substance is produced, *viz.*, s-*dithiocarbimidothiourea*, $CS(NH{\cdot}NCS)_2$.

Of the compounds so far examined, *s*-dicarbamidothiourea gave interesting colour reactions with certain metallic ions. With copper in neutral solution a greenish-grey precipitate is obtained, and in ammoniacal solution small quantities of cupric ion produced a violet-red colour. The smallest quantity of copper capable of systematic identification is 0·25γ in 50 ml. of water. The test should be capable of use as a colorimetric method for estimating small traces of copper, *e.g.*, in water supplies. The substance also gave a deep indigo precipitate with cobalt salts, quantities as small as 1γ being thus recognisable. At this dilution, nickel does not interfere.

The thiocarbazone from *s*-di-(*p*-bromophenyl)thiocarbazide gave reactions with lead similar to those obtainable from diphenylthiocarbazone.

The most interesting compound was s-*diphenyldiureidothiourea*, which gave a deep crimson precipitate on boiling with solutions containing mercuric ion. This precipitate is formed at dilutions of 1 in 10^6 of mercuric ion, at which point neither lead nor silver in concentrations below 1 in 10^3 interferes. The possible application of these reagents to micro-quantitative analysis is being investigated.

EXPERIMENTAL.

1 : 2 : *4-Trithiocarbimidobenzene*, $C_6H_3(NCS)_3$.—Phenylhydrazine (10 g.) in hydrochloric acid (10%; 700 ml.) was shaken with thiocarbonyl chloride (15 g.). On standing for 18 hours, an oily solid separated. The supernatant liquid gave only phenylhydrazine hydrochloride on evaporation. The oily solid was extracted with acetone (20 ml.), and the residue crystallised from benzene, yielding 1 : 2 : *4-trithiocarbimidobenzene*, m. p. 156° (Found : C, 43·4; H, 1·5; S, 38·4. $C_9H_3N_3S_3$ requires C, 43·4; H, 1·6; S, 38·4%). The acetone extract was evaporated and distilled with steam; phenylthiocarbimide was isolated and characterised by conversion into *s*-diphenylthiocarbamide, m. p. 153°.

1 : 2 : *4-Tris(phenylthiocarbamido)benzene*, $C_6H_3(NH{\cdot}CS{\cdot}NHPh)_3$.—1 : 2 : 4-Trithiocarbimidobenzene (4 g.), aniline (4·5 g.), and benzene (100 ml.) were boiled together for 3 hours. On cooling, 1 : 2 : *4-tris(phenylthiocarbamido)benzene* separated; it formed white micro-crystals from benzene, m. p. 120° (Found : S, 18·6. $C_{27}H_{24}N_6S_3$ requires S, 18·2%).

1 : 2 : *4-Tris-(4-bromophenylthiocarbamido)benzene* was prepared in an analogous manner from *p*-bromoaniline; white crystals, m. p. 183° (Found : S, 12·8. $C_{27}H_{21}N_6Br_3S_3$ requires S, 12·6%).

3 : *4-Dithiocarbamidophenylthiourethane*, $C_6H_3(NCS)_2{\cdot}NH{\cdot}CS{\cdot}OEt$.—Trithiocarbimidobenzene (2 g.) was boiled with absolute alcohol (50 ml.) for 10 hours. On cooling, the *compound* separated; white needles from alcohol, m. p. 74° (Found : S, 32·1. $C_{11}H_9ON_3S_3$ requires S, 32·5%).

1 : 3 : *5-Trithiocarbimidobenzene*, $C_6H_3(NCS)_3$.—*s*-Triaminobenzene hydrochloride (15 g.) in dilute hydrochloric acid (700 ml.; 7%) was shaken with thiocarbonyl chloride (15 g.) for 24 hours. The solid which separated was a complex mixture from which ethyl acetate extracted 1 : 3 : *5-trithiocarbimidobenzene*; small white prisms, m. p. 143° (Found : S, 38·2. $C_9H_3N_3S_3$ requires S, 38·4%).

1 : 2 : *4-Trithiocarbamidobenzene*, $C_6H_3(NH{\cdot}CS{\cdot}NH_2)_3$, was precipitated on passing dry ammonia through 1 : 2 : 4-trithiocarbimidobenzene (5 g.) in benzene (50 ml.) until the solution was colourless; it formed white micro-crystals, m. p. 170° (Found : S, 31·8. $C_9H_{12}N_6S_3$ requires S, 32·0%).

2-Amino-1 : 4-dithiocarbamidobenzene, $C_6H_3(NH{\cdot}CS{\cdot}NH_2)_2NH_2$.—1 : 2 : 4-Trithiocarbamidobenzene (5 g.) and hydrochloric acid (20% HCl; 10 ml.) were boiled for 30 hours, hydrogen sulphide being evolved. On cooling, the *compound* separated; white needles, m. p. 149·5° (Found : S, 26·6. $C_8H_{11}N_5S_2$ requires S, 26·6%).

s-*Dicarbamidothiourea*.—Thiocarbonyl chloride (5 g.) in ether (20 ml.) was added to a stirred solution of semicarbazide (14 g.) in water (200 ml.). After 2 hours, the liquid was filtered, and, after a further 18 hours, the *compound* separated; white needles from water, m. p. 215° (decomp.) (Found : C, 19·1; H, 4·3; S, 16·3. $C_3H_8O_2N_6S$ requires C, 18·8; H, 4·2; S, 16·6%).

Compounds of s-*Dicarbamidothiourea with Metals*.—A solution of the reagent (0·2 g.) in aqueous alcohol (50%; 100 ml.) was used. Insoluble compounds were formed with many metals, but only those from copper and cobalt persisted at high dilutions. The results are summarised below, the colour being that obtained with the reagent and ammonia.

Metal ion.	Colour.	Metal ion.	Colour.
Pb	Pale yellow.	Ni	Brown-grey ppt. at high concn.
Ag	Deep blue ppt.	Co	Deep indigo ppt.
Au	Yellow ppt.	Cu	Red-violet.*
Mn	—	Fe	—
Zn	—	Hg'	—

* Greenish-grey without ammonia.

The indigo-coloured precipitate from 1γ of cobalt ion in 50 ml. of water was easily visible in the Lovibond Nessleriser. At a concentration of 4γ in 50 ml. the precipitate was marked. The colour produced with 2·5γ of copper ion in water (50 ml.) is considerably deeper than that produced by rubeanic acid under similar conditions.

3 : *5-Dithiocarbimidothiocarbonyldiurea* (II).—Semicarbazide hydrochloride (12 g.) in water (500 ml.) was shaken with thiocarbonyl chloride (15 g.) for 2 hours. The product was washed with water (500 ml.), ether (200 ml.), and carbon disulphide (200 ml.); yield, 10 g. of pale yellow micro-crystals, m. p. 186—194° (decomp.) (Found : C, 21·9; H, 1·6; S, 34·7. $C_5H_4O_2N_6S_3$ requires C, 21·6; H, 1·5; S, 34·8%). The *compound* was readily reduced by zinc dust and dilute hydrochloric acid to trithioformaldehyde, and was decomposed by dilute alkali to hydrogen sulphide, hydrazine, carbon dioxide, and ammonia.

s-*Diphenyldiureidothiourea*, $CS(NH\cdot NH\cdot CO\cdot NHPh)_2$.—Thiocarbonyl chloride (10 g.) in ether (200 ml.) was well shaken with phenylsemicarbazide (50 g.) in water (2 l.). The *compound* separated after an hour; slender needles, from water, m. p. 223° (Found: S, 9·5. $C_{15}H_{16}O_2N_6S$ requires S, 9·3%).

2-*Thion*-1-*phenyldiurea*, $NHPh\cdot CS\cdot NH\cdot NH\cdot CO\cdot NH_2$.—3 : 5-Dithiocarbimidothiocarbonyldiurea (6 g.), aniline (9 g.), and alcohol (150 ml.) were boiled for ½ hour. On cooling, 2-thion-1-phenyldiurea separated; small white needles, m. p. 198° (Found: S, 15·4. Calc. for $C_8H_{10}ON_4S$: S, 15·3%). On boiling phenylthiocarbimide (2 g.) with semicarbazide (3 g.) in alcohol (50 ml.), the same compound separated in needles, m. p. 198° (Found: S, 15·4%) (Arndt, Milde, and Tschenscher, *Ber.*, 1922, **55**, 341).

The p-*tolyl* analogue, prepared by the action of *p*-toluidine on 3 : 5-dithiocarbimidothiocarbonyldiurea and by heating *p*-tolylthiocarbimide and semicarbazide in alcohol, formed white needles, m. p. 208° (Found: S, 14·5. $C_9H_{12}ON_4S$ requires S, 14·3%); and the p-*bromophenyl* analogue, white plates, m. p. 202° from water (Found: S, 11·3. $C_8H_9ON_4BrS$ requires S, 11·1%).

3 : 5-*Dithiocarbimido*-1 : 1 : 7 : 7-*tetraphenylthiocarbonyldiurea*, $CS[N(NCS)\cdot CO\cdot NPh_2]_2$.—4 : 4-Diphenylsemicarbazide (5 g.) in water (4 l.) containing hydrochloric acid (100 ml.) was stirred with thiocarbonyl chloride (4 g.) for 2 hours. The light yellow solid which separated was washed with ether, dried, and extracted with warm ligroin. On concentration, the solution deposited little yellow micro-crystals, m. p. 133° (Found: S, 16·5. $C_{29}H_{20}O_2N_6S_3$ requires S, 16·4%).

3 : 5-*Bis*(*phenylthiocarbamido*)-1 : 1 : 7 : 7-*tetraphenylthiocarbonyldiurea* (III; R = Ph).—*The foregoing compound (6 g.) and aniline (2 g.) in ligroin (100 ml.) were boiled for ½ hour. The compound* (III; R = Ph) separated on cooling; white needles from alcohol, m. p. 162·5° (Found: S, 12·4. $C_{41}H_{34}O_2N_8S_3$ requires S, 12·5%). It was readily decomposed by boiling 10% hydrochloric acid, giving carbon dioxide, hydrogen sulphide, phenylthiocarbimide, and *as*-diphenylsemicarbazide.

3 : 5-*Dithiourethanocarbonyldiurea*, $CS[N(CO\cdot NH_2)\cdot NH\cdot CS\cdot OEt]_2$.—3 : 5-Dithiocarbimidothiocarbonyldiurea (6 g.) was boiled with absolute alcohol (50 ml.) until a clear solution was obtained (1 hour). The alcohol was removed by distillation, leaving a golden-yellow oil which solidified on cooling (7·5 g.); m. p. 30—32° (Found: S, 25·6. $C_9H_{16}O_4N_6S_3$ requires S, 26·1%). This *compound* (5 g.), aniline (5 g.), and alcohol (50 ml.) were boiled for ½ hour. On cooling, crystals of 2-thion-1-phenyldiurea were deposited. On concentration, the filtered alcoholic solution yielded thiocarbanilide, m. p. 153°. On dry distillation of the compound, alcohol was obtained, and identified by conversion into ethyl benzoate, b. p. 213°.

NN′-*Dithiocarbimido*-NN′-*dioxamylthiourea*.—Semioxamazide hydrochloride (9 g.) in water (400 ml.) was shaken with thiocarbonyl chloride (9 g.). After 2 hours, the *compound* separated, and was washed with water (200 ml.) and ether (100 ml.); light yellow micro-crystals, m. p. 223°, from nitrobenzene (Found: S, 29·25. $C_7H_4O_4N_6S_3$ requires S, 29·0%). Zinc dust and dilute acid reduced the compound to trithioformaldehyde, carbon dioxide, hydrogen sulphide, and ammonia.

1-*Oxamyl*-4-*phenylthiosemicarbazide*, $NHPh\cdot CS\cdot NH\cdot NH\cdot CO\cdot CO\cdot NH_2$.—The foregoing compound (6 g.) and aniline (7·5 g.) in alcohol (100 ml.) were boiled for ½ hour. The *compound* separated on cooling; short white needles from water, m. p. 185·5° (Found: S, 13·6. $C_9H_{10}O_2N_4S$ requires S, 13·5%). It was also formed by boiling phenylthiocarbimide (3 g.), semioxamazide (2 g.), and alcohol (50 ml.); m. p. 185·5° (Found: S, 13·7%). It was hydrolysed by boiling water to phenylthiocarbimide and semioxamazide.

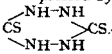
NN′-*Dithiocarbimidodimethylthiourea* (V).—Methylhydrazine sulphate (14 g.) in water (700 ml.) was shaken with thiocarbonyl chloride (15 g.) for 2 hours, during which the *compound* separated; orange micro-crystals, m. p. 139° (Found: S, 44·2. $C_5H_6N_4S_3$ requires S, 44·0%), from ligroin. On boiling with 20% sodium hydroxide solution, it was completely decomposed, forming methylhydrazine, carbon dioxide, and hydrogen sulphide.

4-*Phenyl*-1-*methylthiosemicarbazide*, $NHPh\cdot CS\cdot NH\cdot NHMe$.—The compound (V) (5 g.), aniline (10 g.), and alcohol (50 ml.) were boiled for ½ hour. The first crop of crystals to separate was thiocarbanilide, m. p. 153°, but the second consisted of a mixture of this with 4-phenyl-1-methylthiosemicarbazide. The final filtrate on dilution with water gave the latter compound; white needles, m. p. 143°. Synthesised by boiling methylhydrazine (3 g.) and phenylthiocarbimide (9 g.) in alcohol (100 ml.) for ½ hour, it formed white needles, m. p. 143° (*Ber.*, 1889, **22**, Ref. 670), not depressed by admixture with the previous preparation.

Dithiocarbimidothiourea.—(i) Hydrazine sulphate (12 g.) in water (700 ml.) was shaken with thiocarbonyl chloride (15 g.) for 2 hours. The solid product, washed with ether and water, was

a light yellow solid, insoluble in all ordinary organic solvents. It decomposes at 196—200° (*Found :* S, 50·5. $C_3H_2N_4S_3$ *requires* S, 50·5%).

(ii) A solution of thiocarbohydrazide (5 g.) in hydrochloric acid (250 ml.; 10%) when shaken with thiocarbonyl chloride (6 g.) gave a light yellow powder (Found : S, 50·5%) which decomposed at 195—200°, not depressed by admixture with the compound prepared as in (i).

Dithio-p-*urazine*, —Dithiocarbimidothiourea (5 g.), aniline (9 g.), and alcohol (50 ml.) were boiled for ½ hour. The filtered solution on concentration gave thiocarbanilide, m. p. 153°. Evaporation of the filtrate under reduced pressure gave, on addition of a few drops of concentrated hydrochloric acid, white crystals of dithio-*p*-urazine, m. p. 202—203°. This was also prepared from the product of method (ii), above.

When *p*-toluidine was used instead of aniline in the above experiment, ditolylthiourea, m. p. 177°, and dithio-*p*-urazine were obtained.

Dithio-*p*-urazine was obtained by heating potassium ethyl xanthate (3 g.), alcohol (20 ml.), and thiocarbohydrazide (2 g.) at 100° for 2 hours. The solution on precipitation with a few drops of concentrated hydrochloric acid gave dithio-*p*-urazine, m. p. 202—203° (Guha and De, J., 1924, **125**, 1215) (Found : S, 43·0. Calc. for $C_2H_4N_4S_2$: S, 43·2%).

N-*Thiocarbimidodiphenylamine*, NPh_2·NCS.—*as*-Diphenylhydrazine hydrochloride (30 g.) in water (1½ l.) was shaken with thiocarbonyl chloride (15 g.). After 2 hours, the product was filtered off, dried, and extracted with boiling ligroin. On cooling, long white needles of N-*thiocarbimidodiphenylamine* separated, m. p. 63° (*Found :* S, 14·6; *M*, *cryoscopic in benzene*, 236. $C_{13}H_{10}N_2S$ requires S, 14·2%; *M*, 226). No reaction with alcohol could be induced, and with aniline no isolable product was obtained.

N-*Thiocarbimidophenylmethylamine*, NPhMe·NCS.—Phenylmethylhydrazine in hydrochloric acid (5% HCl; 1 l.) was shaken with thiocarbonyl chloride (11 g.) for 2 hours. The oil was separated, extracted with ether, and the solution dried over anhydrous potassium carbonate. The filtered solution, on evaporation, gave N-*thiocarbimidophenylmethylamine* as a brown unstable oil (10 g.) (Found : S, 19·2. $C_8H_8N_2S$ requires S, 19·5%). On distillation in a vacuum, phenylthiocarbimide was produced. The oil (5 g.) when heated with aniline (5 g.) in alcohol (100 ml.) for ½ hour gave 1 : 4-diphenyl-1-methylthiosemicarbazide, m. p. 154°, together with thiocarbanilide and phenylthiocarbimide.

NN'-*Dithiocarbimidobis*-p-*nitrophenylthiourea*, $CS[N(C_6H_4{\cdot}NO_2){\cdot}NCS]_2$.—*p*-Nitrophenylhydrazine (7·6 g.) in hydrochloric acid (10%; 700 ml.) was shaken with thiocarbonyl chloride for 10 hours. The solid product, washed well with ether and water, crystallised from glacial acetic acid as light brown micro-crystals (Found : S, 22·3. $C_{15}H_8O_4N_6S_3$ requires S, 22·2%); it readily reacted with benzidine in alcohol, and readily dissolved in 2*N*-sodium hydroxide, forming a deep brown solution. With tin and hydrochloric acid, ammonium chloride, hydrogen sulphide, trithioformaldehyde, and *p*-phenylenediamine hydrochloride were formed.

NN'-*Diphenylthiocarbamidobis*-p-*nitrophenylthiourea*.—The above thiourea (3 g.) and aniline (3 g.) in alcohol (100 ml.) were boiled for 2 hours. After concentration, the filtrate, on addition of water, gave white plates of NN'-*diphenylthiocarbamidobis*-p-*nitrophenylthiourea*, m. p. 143° (Found : S, 15·0. $C_{27}H_{22}O_4N_8S_3$ requires S, 15·5%), which turned red on standing. Hydrolysis with 2*N*-hydrochloric acid gave phenylthiocarbimide, *p*-nitrophenylhydrazine hydrochloride, carbon dioxide, and hydrogen sulphide.

3 : 5-*Dithiocarbimidothiocarbonyldithiourea*, $CS[N(NCS){\cdot}CS{\cdot}NH_2]_2$.—Thiosemicarbazide (6·5 g.) in hydrochloric acid (1% HCl; 400 ml.) was shaken with thiocarbonyl chloride (11 g.). After 4 hours the orange precipitate was filtered off, washed with ether (100 ml.) and water (500 ml.), and dried; it formed orange micro-crystals, m. p. 240—250° (decomp.) (Found : S, 52·0. $C_5H_4N_6S_5$ requires S, 52·0%).

Dithiourazole.—The previous *compound* (4 g.) was heated with aniline (5 g.) and alcohol (30 ml.) on the water-bath for ½ hour, the mixture poured into water (400 ml.), and the thiocarbanilide which separated was filtered off and recrystallised; m. p. 153°. The aqueous-alcoholic filtrate on evaporation to 20 ml. gave, on cooling, broad prisms of dithiourazole, m. p. 245°, not depressed by admixture with authentic dithiourazole (*Found :* S, 48·0. *Calc. for* $C_2H_3N_3S_2$: S, 48·1%).

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277. *The Influence of Substituents on the Coupling of Phenols with Diazonium Salts.*

By Donald H. Richardson.

A convenient method of measuring the relative polar effects of the halogens in the benzene ring is afforded by coupling *p*-nitrobenzenediazonium sulphate with the equivalent quantity of phenol in competition with the equivalent quantity of halogenophenol. Coupling velocity ratios relative to phenol may be calculated from the composition of the mixed dyes determined by estimation of halogen. By coupling competitions between other substituted phenols and *o*-bromophenol the polar effects of other groups meta or ortho to the coupling position may be compared with those of bromine, and hence with hydrogen in unsubstituted phenol. The results obtained confirm the current view that chlorine in aromatic combination exerts a more powerful deactivating (inductive) effect than bromine, and further show that the ratio of the effects of the two halogens is very nearly the same whether they are meta or ortho to the coupling position. Iodine activates the coupling position, but not very much more when ortho than when meta to it, and this result suggests that activating effects, presumably mesomeric or electromeric, may be transmitted to a meta position more powerfully than has been suggested. Competitive coupling between guaiacol and *o*-bromophenol shows that the methoxyl group exerts a very powerful activating effect upon the coupling position meta to it, and this is compared with the much weaker activating inductive effect due to methyl by competition between *o*-cresol and *o*-bromophenol.

Preliminary experiments showed that the halogenophenols (with the exception of *p*-bromo- and -iodo-phenols), when coupled with the equivalent quantity of *p*-nitrobenzenediazonium sulphate in dilute solution, give good yields of azo-compounds which, without any purification, contain not less than 96% of the theoretical amount of halogen for the pure dye. Thus the composition of mixed dyes obtained by coupling the diazonium salt with the equivalent quantity each of phenol and a halogeno-phenol could be determined with fair accuracy by estimation of halogen. Analyses were made of mixed dyes prepared from phenol and *o*- and *m*-chloro-, -bromo-, and -iodo-phenols, and the results were checked by competition couplings between *o*-chloro- and -bromo-phenols, and *o*-bromo- and -iodo-phenols. Mixed halogen analyses of the products gave coupling ratios closely agreeing with those calculated from the competitions with phenol. The effect of two halogen atoms on the coupling reaction was investigated by competition between 2 : 6-dichloro- and 2 : 6-dibromo-phenol, and the coupling ratios were unchanged when benzenediazonium sulphate was substituted for *p*-nitrobenzenediazonium sulphate.

The coupling reaction having been proved to be bimolecular (Conant and Peterson, *J. Amer. Chem. Soc.*, 1930, **52**, 1220), the coupling velocity of each halogenophenol relative to that of phenol can be calculated from the molecular composition of the mixed dye by means of the equation developed by Ingold and Shaw (J., 1927, 2922), *viz.*,

$$\frac{k_y}{k_x} = \log\left\{1 - \frac{z_0}{y_0}\left(\frac{R}{1+R}\right)\right\} \Big/ \log\left\{1 - \frac{z_0}{x_0}\left(\frac{1}{1+R}\right)\right\}$$

where R is the molar ratio in which phenol and halogenophenol couple, and x_0, y_0, and z_0 are the initial concentrations of phenol, halogenophenol, and diazonium salt respectively. *o*-Chloro- (0·51), *m*-chloro- (0·36), *o*-bromo- (0·84), and *m*-bromo- (0·63) phenols couple more slowly, and *o*-iodo- (1·13) and *m*-iodo- (1·24) phenols more rapidly than phenol to the extent indicated in parentheses. These results confirm the current view that the halogens exert a deactivating inductive effect decreasing from chlorine to bromine, and afford clear evidence of an activating effect in the case of iodine. If this effect is mesomeric or electromeric in nature, its transmission by iodine meta, as well as ortho, to the coupling position would indicate that these effects reach the *m*-position with greater force than has been suggested (*e.g.*, Jones, J., 1935, 1838).

To test this point, competitive couplings were made between *o*-bromophenol and

guaiacol, and *o*-bromophenol and *o*-cresol. Determination of bromine in the mixed dyes obtained gave coupling ratios relative to *o*-bromophenol, and from the coupling velocity of the latter relative to phenol it is calculated that guaiacol couples 28·4 and *o*-cresol 6·6 times as fast as phenol. The meta (coupling) position is thus much more powerfully activated by the mesomeric and electromeric effects of the methoxyl group than by the inductive effect of the methyl group. It may be noted that the deactivating effect of chlorine is greater than that of bromine in very nearly the same ratio (1·7 : 1) whether the halogen is meta or ortho to the coupling position, and that the deactivating effect of two *m*-chlorine atoms does not exceed that of two *m*-bromine atoms by much more than this amount. The latter result suggests that the process by which the deactivating effect reaches the coupling position cannot operate on both sides of the benzene ring simultaneously.

EXPERIMENTAL.

o-Chloro and o-bromo-phenols (purchased as pure) were redistilled, and o-iodophenol was prepared from *o*-chloromercuriphenol ("Organic Syntheses," Vol. IV, 13). 2 : 6-Dichloro- and -dibromo-phenols were prepared by chlorinating or brominating *p*-hydroxybenzoic acid in cold glacial acetic acid (Zincke and Walbaum, *Annalen*, 1891, **261**, 208) and heating the product with quinoline as described by Blicke, Smith, and Powers (*J. Amer. Chem. Soc.*, 1932, **54**, 1468), except that a lower temperature (160°) was found advantageous. The author is indebted to Mr. C. Hinkley for the first two preparations, Mr. B. A. Bleiweis for the third, and Messrs. J. C. Morpeth and W. Reis for the preparation of the *m*-halogenophenols from *m*-nitroaniline.

To prepare the azo-dyes, 6·9 g. of *p*-nitroaniline (0·05 mol.) in 82·5 c.c. of glacial acetic acid were diazotised with 3·8 g. of sodium nitrite in 26·5 c.c. of concentrated sulphuric acid (Hodgson, J., 1933, 1620), and one half of the solution poured into an $N/100$-solution of the halogenophenol (0·025 mol.) and phenol (0·025 mol.) in 2500 c.c. of ice-cold $N/2$-sodium hydroxide, the other half being coupled with the halogenophenol alone under similar conditions. After standing for several hours, the clear solutions were acidified, and the precipitated dyes collected, washed, and dried. With one exception the yields of azo-dye were not less than 80% of the theoretical calculated on the assumption that the *p*-nitroaniline was quantitatively diazotised.

$NO_2{\cdot}C_6H_4{\cdot}N_2{\cdot}SO_4H$ coupled with	Yield, %.	Purity of azo-dye, %.	Mol. coupling ratio. Phenol = 1.	Coupling velocity *ratio.* Phenol = 1.
o-Chlorophenol	81	96·0	—	—
,, + PhOH	81	—	0·63	0·51
o-Bromophenol	88	98·1	—	—
,, + PhOH	—	—	0·89	0·84
o-Iodophenol	97	96·8	—	—
,, + PhOH	88	—	1·09	1·13
m-Chlorophenol	92	97·4	—	—
,, + PhOH	88	—	0·50	0·36
m-Bromophenol	74	*100*	—	—
,, + PhOH	82	—	0·73	0·63
m-Iodophenol	80	97·8	—	—
,, + PhOH	—	—	1·16	1·24
			o-Bromophenol = 1.	*o*-Bromophenol = 0·84.
o-Chloro- + *o*-bromo-phenol	86	—	0·70	0·50
o-Iodo- + *o*-bromo-phenol	93	—	1·19	1·09
2 : 6-Dichlorophenol	97	98·1	—	—
2 : 6-Dibromophenol	93	98·4	—	—
			2 : 6-Dibromo-phenol = 1.	2 : 6-Dibromo-phenol = 1.
2 : 6-Dichlorophenol + 2 : 6-dibromophenol	85	—	0·65	0·54
Do. coupled with $C_6H_5{\cdot}N_2{\cdot}SO_4H$	—	—	0·65	0·54
			o-Bromophenol = 1.	*o*-Bromophenol = 0·84.
o-Cresol	84	—	—	—
,, + *o*-bromophenol	88	—	4·23	6·6
Guaiacol	84	—	—	—
,, + *o*-bromophenol	91	—	12·45	28·4

The halogen in both pure and mixed dyes was determined by heating 0·5 g. dissolved in 100 c.c. of $N/10$-potassium hydroxide with 10 g. of potassium permanganate on the steam-bath for 5 hours, the halogen being eliminated from the phenolic ring on account of the complete oxid-

ation of the latter. Addition of excess sulphurous acid gave a perfectly clear solution in which the halogen was estimated gravimetrically. Mixed halogens were determined from the weight of mixed silver halide precipitated by a weighed amount of silver nitrate, the excess of which was estimated as silver bromide.

The results are tabulated on page 1364.

NORTHERN POLYTECHNIC, HOLLOWAY ROAD, N. 7. [*Received, December 11th, 1936.*]

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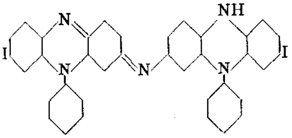
278. *The Reaction between Aniline and Iodine.*

By HERBERT H. HODGSON and EWART MARSDEN.

The present study has indicated that temperature plays an important part in the reaction between iodine and aniline. Below 150° iodination alone occurs, whereas above 150° the oxidising rôle of the iodine appears and proceeds with increasing intensity until from 180° to 230° appreciable amounts of a dark blue product are formed. This coloured compound is regarded as possessing the formula inset below, and has been alternatively prepared by heating *p*-iodoaniline with aniline at 220—230°.

FRITZSCHE (*J. pr. Chem.*, 1840, **20**, 454; 1843, **28**, 202) and Hofmann (*Annalen*, 1848, **67**, 65) have previously studied the reaction between aniline and iodine, and among the products have identified aniline hydriodide and a monoiodoaniline. Subsequent investigators, however, intent on the preparation of *p*-iodoaniline in good yield, have all utilised a third substance to decompose the hydrogen iodide liberated (cf. "Organic Syntheses," Vol. XI, New York, 1931, p. 62). In view of the oxidising rôle which the iodine may fulfil, the present investigation has been undertaken to elucidate the mechanism of direct iodination.

Various amounts of aniline and iodine were heated together at temperatures ranging from 20° to 230° (see table), and it was found that from 20° to 150° the main products were *p*-iodoaniline and aniline hydriodide, if molecular quantities were taken, but that 2 : 4-di-iodoaniline occurred with increasing amounts of iodine. At higher temperatures, a dark blue product was formed, which was identified as a single substance with a probable aposafranine formula (inset). This coloured compound, which has vat dye properties, has been alternatively synthesised by heating *p*-iodoaniline with aniline, but when carefully purified *p*-iodoaniline was heated alone, there resulted only 2 : 4-di-iodoaniline and free iodine.



The mechanism of the reaction at the higher temperatures would thus appear to be the initial formation of *p*-iodoaniline with subsequent oxidation in presence of aniline to an iodohydroaposafranine, two molecules of which condense with diarylamine formation and final oxidation to the complex indamine.

EXPERIMENTAL.

General Iodination Procedure.—Iodine was added gradually to vigorously stirred aniline during 20 minutes, the mixture being maintained at a constant temperature, and the agitation continued for 30 minutes after complete dissolution of the iodine had occurred. When cold, the product was washed 12 times with cold water (400 c.c. per time) to remove aniline hydriodide, then dissolved in hot (80°) concentrated hydrochloric acid (*d* 1·16) in sufficient amount for the solution to give a distinctly acid reaction with Congo-red paper. After filtration, the hot filtrate was chilled rapidly to 5—10°, whereupon a greenish crystalline mixture of the hydrochlorides of the iodoanilines separated, and was filtered off.

The insoluble tarry matter was dried, dissolved in aniline, and recovered in a more workable condition by removal of the aniline by dilute hydrochloric acid.

The crude hydrochlorides above were stirred with hot water at 80° (500 c.c. per 0·5 g. of iodine originally used); the *p*-iodoaniline hydrochloride dissolved, the solution was filtered,

and the filtrate treated with sulphuric acid, whereby *p*-iodoaniline sulphate separated on cooling to 5—10°, and, on basification by trituration with hot dilute sodium carbonate, afforded *p*-iodoaniline, which crystallised from alcohol in colourless needles, m. p. 63° (lit. 63°) (Found : N, 6·4. Calc. for C_6H_6NI : N, 6·4%). The solubility of *p*-iodoaniline in water at 12° is 0·65%. The oily residue of 2 : 4-di-iodoaniline left after the water extraction was crystallised from 80% aqueous acetic acid, and obtained in pale yellow needles, m. p. 95° (Found : N, 4·0; *M*, by nitrite titration, 335. Calc. for $C_6H_5NI_2$: N, 4·1%; *M*, 345). If the amount of 2 : 4-di-iodoaniline is very small, the glacial acetic acid extract of the oily residue above is diluted with an equal volume of water, and the base salted out by addition of sodium acetate. Since free iodine was always present in the *p*-iodoaniline thus obtained, notwithstanding variations in the amount of iodine employed, and also since its amount increased with time, it was necessary to perform the above operations as rapidly as possible.

Table of Results.

Expt.	NH_2Ph, g.	I, g.	Mol. ratio, NH_2Ph/I.	Temp.	*p*-Iodo-aniline, g.	2 : 4-Di-iodo-aniline, g.	NH_2Ph,HI, g.
1	10·0	6·85	2·0	40°	5·7	0·10	5·8
2	21·5	15·75	1·86	60	10·2	3·50	15·7
3	20·0	27·3	1·00	80—100	Nil	22·50	19·2
4	10·0	13·5	1·01	20—40	10·6	0·03	11·9
5	20·0	6·5	4·2	27—32	4·8	0·27	5·2
6	20·1	6·0	4·6	30—35	4·7	0·37	5·2
7	19·99	6·0	4·55	40—45	4·9	0·26	5·2
8	20·1	6·0	4·6	50—55	4·9	0·07	5·1
9	20·05	6·0	4·58	90—95	4·8	0·14	5·0
10 *	10·0	6·0	2·28	130—150	4·9	0·14	5·2
11 †	10·0	6·0	2·28	180—230	Nil	Nil	12·0

* In this experiment, 0·004 g. of a red, insoluble residue was obtained.
† 2·75 G. of a blue insoluble residue were obtained.

Discussion.—(1) All the experiments except Nos. 2, 3, and 11 give data in conformity with the equation

$$2C_6H_5{\cdot}NH_2 + I_2 = I{\cdot}C_6H_4{\cdot}NH_2 + C_6H_5{\cdot}NH_2,HI.$$

Expt. 10 appears to indicate aposafranine formation.

(2) Expt. 3 is represented by the equation

$$3C_6H_5{\cdot}NH_2 + 2I_2 = C_6H_3I_2{\cdot}NH_2 + 2C_6H_5{\cdot}NH_2,HI$$

and expt. 2 is represented by a combination of both equations. The total weight of insoluble matter recovered from all the experiments 1—10 was only 0·034 g.

The Dyestuff from Experiment 11.—The dark blue residue was thoroughly washed with water, dried, and found to be very insoluble in all the ordinary solvents; it was moderately soluble, however, in α-naphthylamine, cellosolve, and aniline, giving indigo-blue solutions, from the last of which it crystallised in violet-blue micro-crystals which decomposed on heating [Found : N, 8·9; I, 32·4; *M*, cryoscopic in α-naphthylamine (constant 89·5), 758. $C_{36}H_{22}N_5I_2$ requires N, 9·0; I, 32·6%; *M*, 779]. This *product* dissolved in cold concentrated sulphuric acid to give a deep blue solution which was not diazotised by nitrous acid and did not become red on dilution, as in the case of safranine; the colour was precipitated as a fine suspension on dilution, and unmordanted wool immersed in this suspension was dyed in fugitive blue shades which were discharged on treatment with zinc dust and acetic acid but returned on subsequent exposure to air. Dry distillation with zinc dust produced ammonia, carbylamine, aniline, and a sublimate (0·5 g. from 3 g. of dye) of yellow crystals of phenazine, m. p. 170·5° (Found : N, 15·7. Calc. for $C_{12}H_8N_2$: N, 15·5%).

Synthesis of the Above Dye from p-*Iodoaniline and Aniline.*—A mixture of *p*-iodoaniline (2·0 g.) and aniline (0·1 g.) was heated under the reflux for 30 minutes at 220—230°. The liquid gradually darkened, and the dark blue product obtained on cooling was washed with hot dilute sulphuric acid to remove unchanged amine (none detected) and aniline hydriodide (0·0954 g.), then with hot glacial acetic acid to remove 2 : 4-di-iodoaniline (1·32 g.) and free iodine (0·15 g.), and finally recrystallised from aniline. It proved to be identical with the product above from direct iodination (Found : N, 9·0; I, 32·5%; *M*, 762).

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TECHNICAL COLLEGE, HUDDERSFIELD. [*Received, June 22nd, 1937.*]

279. *The Preparation of Ytterbous Sulphate and its Elimination from Lutecium Sulphate.*

By Joseph K. Marsh.

Amalgamated lead may replace mercury as cathode for reduction of ytterbium sulphate, and a 95% yield of ytterbous sulphate is obtained. Four precipitations raise the purity from 30% to 100%. Freedom of electrolyte from heavy metals, and purity of cathode materials are essential. Similarly 95% lutecium oxide has been prepared from ytterbium–lutecium mixtures.

Hitherto, ytterbous sulphate has been prepared at a mercury cathode and only in small quantities (Ball and Yntema, *J. Amer. Chem. Soc.*, 1930, **52**, 4264; Prandtl, *Z. anorg. Chem.*, 1932, **209**, 13; Pearce, Quirke, and Hopkins, *Amer. J. Sci.*, 1935, **30**, 116; Pearce, Naesen, and Hopkins, Preprints Electrochem. Soc., 1936). It is now found that electrodes of amalgamated lead are more convenient, and may be employed successfully in cells of low resistance, but the purity of the lead is a matter of prime importance, and the freedom of the electrolyte from heavy metals a factor upon which the stability of the reduced salt is largely dependent. The presence of heavy metals is indicated if, when reduction starts, a darkening of the solution takes place. This darkening has been observed by previous workers, and the great instability of the ytterbous sulphate which has been noted is due in large measure to the catalytic oxidising action of the impurity. An ytterbous sulphate solution, free from solid and not unduly exposed to air, remains green for several hours, and if some undissolved salt is also present the evolution of hydrogen is very slow. If, however, the crop of ytterbous sulphate is contaminated with reduced lead or mercury, the evolution of gas is extremely rapid and the salt will decompose in a few minutes, so that a large part of the yield is lost before it is possible to collect it on a Buchner funnel. The objectionable matter is held on the precipitate, however, so that one or two filtrations remove it, and thereafter the reduction proceeds with greater rapidity.

Further reduction is very slow when the ytterbium oxide content of the solution falls to 10—15 g./l. This represents about 95% efficiency, with a concentrated sulphate solution initially, and marks the usual limit to which it is worth working.

Ytterbium acetate undergoes ready reduction in presence of acetic acid when treated with sodium amalgam. Addition of sulphate ion then gives a precipitate. Owing to difficulties in recovering the rare earth in presence of much sodium, it is doubtful if this method of reduction can compete in utility with the electrolytic.

A lutecium preparation was purified as far as possible by the removal of ytterbous sulphate. The crude oxide contained 70% Lu_2O_3, and this was raised to 95%. The final solution contained 250 g./l. Lu_2O_3, but the same limit for removal of ytterbium was obtained (10—15 g./l. Yb_2O_3) as when ytterbium was present alone in solution. Fractionation methods for the purification of lutecium have hitherto not been very successful, so an easy method of obtaining preparations of 95% purity is of value.

Experimental.

8·6 Kg. of rare earths from Norwegian gadolinite were made into chloride solution. 50 Kg. of sodium sulphate were added gradually during a month, and the precipitate removed from time to time. The cerium earths, nearly all the gadolinium and dysprosium, and much of the yttrium were thus removed, but erbium, ytterbium, and lutecium remained almost wholly in solution. They were, however, precipitated almost quantitatively on boiling. These earths were then transformed into nitrates, and basic nitrates cropped systematically, at first by the addition of sodium hydroxide, but later, when the bulk had been reduced, by the nitrate fusion process. Very quickly, much nearly colourless material collected in the most weakly basic fractions, and formed the starting material for the preparation of pure ytterbium oxide.

The crude oxide was made into a concentrated sulphate solution, either by treating a suspension with sulphuric acid and mechanically stirring it, any great rise of temperature being avoided, or by precipitating the sulphate from a concentrated chloride solution with excess of sulphuric acid and subsequent addition of alcohol. Reduction to ytterbous sulphate was

effected in a 400-ml. tall-form beaker containing a porous pot (106 × 37 mm.). The anode in the pot was a 15-cm. length of stout lead pipe, of 13-mm. bore, closed at the lower end and with a side tube near the top. The cathode in the beaker was a flag (100 × 45 mm.) of pure lead sheet (99·995%) which had been repeatedly amalgamated with pure mercury. A cathode which contained a small amount of tin was found to be quite useless.

The cell rested in 4 or 5 turns of 13-mm. lead pipe suspended in water in a 1·5-l. beaker. During the electrolysis, cooling water was passed through the lead coil and the interior of the anode. Dilute sulphuric acid filled the anode chamber, and up to 200 ml. of sulphate solution were placed in the cathode compartment. No reduction occurred if the electrolyte was not sufficiently acid. The exact degree of acidity was not critical, but from $2N$ to $N/2$ was found suitable. Up to six cells were used in series supplied by a 100-volt main and a cathode current density of 0·3 amp./cm.². At first, reduction was conducted intermittently, the electrolyte being entirely withdrawn for filtration from the accumulated ytterbous sulphate. The current efficiency with concentrated solutions was high, little hydrogen being evolved. When the solution became dilute the electrolysis was made continuous, the reduced salt being withdrawn with a part of the electrolyte by means of a probe, but the cathode was left covered to avoid possibility of corrosion. A heavy crop of ytterbous sulphate was produced in the first 10 minutes, and the reaction brought to completion in 2—3 hours. Starting with material showing strong erbium absorption bands, four reductions were necessary to eliminate all trace of them. A yield of 200 g. of ytterbium oxide was obtained.

Lutecium Preparation.—The material which had not suffered reduction was converted into bromate and recrystallised about 3000 times. The bulk, however, consisting of an yttrium–erbium mixture, was eliminated during the course of this fractionation, and there finally remained at the head crude thulium, in the middle ytterbium which had escaped reduction, and at the tail a mixture of lutecium and ytterbium. The separation of lutecium from ytterbium is not so satisfactory as the separation of thulium, but although the solubility of these bromates is high, they crystallise well, and if the mass of crystals is broken up and allowed to settle, the mother-liquor may be decanted.

The tail fractions (36 g.) which contained only traces of thulium were converted into sulphate (Tm absorption band λ 6830, visible but only weak in 6·5 cm. of 1000 g./l. solution of oxide). A modified reduction cell suitable for handling smaller quantities of precious material was used. The porous pot was replaced by a parchment bag (70 × 20 mm.) attached to a short piece of glass tube. A stout lead wire acted as anode. The glass tube passed tightly through a beaker cover of vulcanite. The outer vessel was a 200-ml. tall-form beaker, cooled by melting ice. The cathode size remained unchanged. When, as here, only one or two cells were in use, a 10-volt supply sometimes replaced the mains. On electrolysis, 9 g. of ytterbium oxide were removed, and a measurement of the magnetic susceptibility of the resultant lutecium oxide showed a purity of 95%.

The author thanks Professor H. E. Watson, through whose instrumentality the gadolinite was opened up, and Professor Sugden, to whom he is indebted for measurements of magnetic susceptibility.

THE OLD CHEMISTRY DEPARTMENT, THE MUSEUMS, OXFORD. [*Received, July 10th, 1937.*]

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280. *The Methyleneimines: Determination of Parachor.*

By DENIS DICKINSON and JOHN GRAYMORE.

The methyleneimines resulting from the condensation of primary amines with formaldehyde were prepared pure in order that their parachors might be determined by the method of Sugden. Parachor determinations, using Sugden's constants, showed them to be cyclic trimethylenetriamines. The *iso*propyl and the *iso*butyl compound gave low parachor results. Calculation of the parachor by Mumford and Phillips's method showed that an increasing value must be given to the alkyl group attached to the nitrogen atom, rising to a maximum with the propyl derivative.

THE condensation product of methylamine and formaldehyde was originally examined by Henry (*Bull. Acad. sci. Belge*, 1885, **26**, 200) who ascribed to it the formula NMe:CH$_2$.

As a result of the work of Brocher and Cambier (*Compt. rend.*, 1895, **120**, 449; see also Duden and Scharff, *Ber.*, 1895, **28**, 936), the cyclic formula $(NR\cdot CH_2)_3$ is now generally accepted for the products obtained by the condensation of the aliphatic primary amines with formaldehyde in the presence of alkalis. The property of these bases, particularly the lower members, of slow decomposition with liberation of formaldehyde, and their ready decomposition by dilute acids, but not by alkalis, suggest a possibility of the existence of an equilibrium of the type $(NR\cdot CH_2)_3 \rightleftharpoons 3NR{:}CH_2$.

This view is supported by the slow oxidation of the bases by air, or more rapidly by permanganate and hydrogen peroxide, to give small quantities of the corresponding *iso*cyanides, an oxidation which would not be expected to proceed if the base were wholly in the cyclic form. Ebullioscopic determinations, although in general favouring the cyclic formula, are invariably considerably below the theoretical.

In view of this uncertainty, it was deemed advisable to measure the parachors of the pure liquids. In addition, since Mumford and Phillips (J., 1929, 2112) were unable to confirm their view that "the differing strain in heterocyclic compounds might be expected to show in the deviation of their parachors from the normal" owing to lack of data, it seemed that the present series would exhibit such constitutive variations if real.

EXPERIMENTAL.

Preparation of the Bases.—All the bases used, except the *iso*propyl compound, have been previously described (J., 1931, 1490; 1932, 1353; 1935, 865).

*iso*Propylamine was prepared from acetone by reduction of its phenylhydrazone with sodium amalgam in alcohol–acetic acid solution, but the yield was much smaller than stated (Tafel, *Ber.*, 1886, **19**, 1926). The amine (1 mol.) was added slowly with cooling to formaldehyde (40%; 2½ mols.). Rise of temperature occurred with each addition, and the product which first formed dissolved. Finally, it formed an emulsion, and separated as an oily layer on the surface on the addition of excess alkali. It was left for 24 hrs. with intermittent shaking in order to complete the separation. The iso*propylmethyleneimine* was removed by extraction with ether, the extract dried (barium oxide), the ether removed, and the residue carefully distilled. It was obtained as a colourless oil, b. p. 220°, $d^{18°}$ 0·8961 [Found: N, 19·7; *M*, 196. $(C_4H_9N)_3$ requires N, 19·7%; *M*, 213].

Purification of the Bases.—The results obtained with the bases prepared as described above gave preliminary parachor values some 6 units below those calculated for the cyclic structure on the basis of Sugden's constants. Since the bases had been prepared some time previously and a distinct smell of *iso*cyanide was noticeable, they were redistilled from barium oxide, traces of a low-boiling product with a strong *iso*nitrile smell being removed. When low results were obtained in later determinations of a series, such products were always present in the base. The accuracy is thus affected by these traces of oxidation product, so great care was taken to obtain consistent results by distillation immediately before use, and also after a few readings were taken.

Parachor Determinations and Calculation.—The surface tension was measured by the method of maximum bubble pressure (J., 1922, **121**, 855; 1924, **125**, 27) with a cell of the Sugden type. The apparatus was calibrated by benzene, purified by freezing and fractionation. The diameter of the wide tube was 0·205 cm., and the cell constants ($A \times 10^3$) were: series I 7·033; series II 6·840; series III 6·811. The gauge contained a dilute solution of magenta in alcohol. The rate of bubbling was adjusted so as to give a clearly distinguishable rise to a strictly reproducible maximum in each case. The temperatures of the gauge and bubbler were varied independently. Density was measured by a pyknometer, of bulb capacity about 9·4 c.c., calibrated over a range of temperature by means of pure mercury, and checked by boiled-out water.

Parachors have been calculated from the formula $[P] = M\gamma^{\frac{1}{4}}/D$, in which the terms have their usual significance. The results are recorded in cols. 1—6 of the table, the subscript I referring to the open-chain structure $NR{:}CH_2$, and II referring to the ring structure $(NR\cdot CH_2)_3$.

DISCUSSION.

Examination of the differences based on Sugden's constants (cols. 7—10) makes it clear that the results are decidedly in favour of the cyclic structure for the compounds when the "calculated" values are derived from these constants. The small differences

						S.'s constants.				M. and P.'s constants.	
				[P], obs.		[P], calc.		Diff.		[P], calc.	
R.	$d^{18°}$.	$\gamma^{18°}$.	M_{II}.	I.	II.	I.	II.	I.	II.	II.	Diff.
Me	0·9218	30·17	129·1	109·4	328·3	130·8	328·9	−21·4	− 0·6	339·5	−11·2
Et	0·8958	29·00	171·2	147·8	443·5	169·8	445·9	−22·0	− 2·3	459·5	−16·0
Pr	0·8799	28·71	213·2	187·0	560·9	208·8	562·9	−21·8	− 2·0	579·5	−18·6
Bu	0·8723	29·29	255·3	227·0	680·9	247·8	679·9	−20·8	+ 1·0	699·5	−18·6
Pr^{β}	0·8961	29·11	213·2	184·2	552·8	208·8	562·9	−24·6	−10·1	570·5	−17·7
Bu^{β}	0·8578	26·23	255·3	222·4	673·4	247·8	679·9	−25·4	− 6·5	690·5	−17·1

S = Sugden; M = Mumford and Phillips.

existing between observed and calculated values for the cyclic structure (cols. 6 and 8) do not appear to give any real evidence in favour of the existence of an equilibrium between the two forms in the pure liquids. The *iso*-compounds show the deviation from the normal which is usual in this type of compound.

When the parachors for the polymeric form are calculated on the basis of Mumford and Phillips's standards (col. 11), it is found that the differences in the last column are much greater than those in col. 10. An allowance of — 3·0 units is included in the calculation of the parachor for a branched chain, making a total allowance of — 9·0 units in each of the two *iso*-compounds examined. Since a normal value of 0·8 may be assigned to the six-membered ring in piperidine (Mumford and Phillips, *loc. cit.*), it was assumed that the same value would be applicable to the parent base, cyclic methyleneimine, $(NH{\cdot}CH_2)_3$, which has not yet been prepared

Consequently, it will be necessary to introduce a strain constant of — 3·0 units for each grouping in which hydrogen originally attached to nitrogen is replaced by an alkyl group, making a total of — 9 units for each compound. The differences recorded in the last column show a variation even after this correction, suggested by Mumford and Phillips, has been made. The difference is slight for the methyl derivative, but increases on ascending the series to a maximum with the *n*-propyl derivative.

Beck, Macbeth, and Pennycuick (J., 1932, 2258) proved that the monosubstituted malonic esters show a decrement which increases to a maximum with the butyl derivative. The decrement was even greater in the case of the disubstituted esters. They suggested that the constitutive effect might be attributed to the consequent decrease in the angle between two carboxyl groups, caused by the substitution of methylenic hydrogen by alkyl groups.

In the present cases we may assume that, in substituting the hydrogen attached to the nitrogen atom in the six-membered ring $(CH_2{\cdot}NH)_3$ by larger groups, these groups, as suggested by Ingold and Thorpe (J., 1921, 119, 306), tend to reduce the valency angle in the ring, thus setting up a strain which increases in magnitude on ascending the series as far as the propyl derivative. It is not unreasonable to postulate a maximum with the propyl base, for it is readily seen that with this derivative the alkyl chain approaches most nearly to the hydrogens of the adjacent CH_2 groups within the ring, thus setting up a maximum strain: as expected, the *iso*-compounds with shorter chains should show a smaller decrement.

It is noteworthy that the maximum decrement of about 18 units approximates closely to that which might be assigned to a tritertiary amine.

The authors thank Prof. Sugden for his kind advice in regard to the practical measurements.

Stockport College. [*Received, July 10th*, 1937.]

281. *Gallium. Part II. The Extraction of Gallium and Germanium from Germanite.*

By F. SEBBA and W. PUGH.

Of the methods previously described for the extraction of germanium and gallium from germanite, none yields gallium in a reasonable time. All the methods make use of acid to decompose the ore, and the gallium must subsequently be separated from very large amounts of copper, iron, lead, and zinc. There is reason to believe, too, that these methods fail to extract gallium completely. The expectation that alkali digestion should extract the two rare elements has been fully realised, and by the method now described it is shown that both germanium and gallium can be easily extracted from the mineral and separated from each other and from arsenic. The method is quick, can be employed on a large scale, and, moreover, gives much larger yields of gallium than have ever been reported in germanite. Analysis of the mineral by this method showed it to contain 1·2% of gallium. The yield in practice is 10 g. per kg. The germanium is obtained as crude oxide, free from arsenic, and needs only simple distillation with hydrochloric acid to yield pure germanium dioxide.

SINCE the discovery of germanite (Schneiderhohn, *Met. Erz*, 1920, **17**, 364) many methods have been described for extracting the rare elements germanium and gallium therefrom. In the first method (Thomas and Pugh, J., 1924, **125**, 816), the roasted ore was distilled with hydrochloric acid, the volatile germanium tetrachloride being collected, and the distillation residues were treated for recovery of gallium. In a modified method, Pugh (J., 1929, 2540) decomposed the ore with nitric acid, thereby concentrating the germanium as the insoluble oxide, which was subsequently distilled with hydrochloric acid. Although this method worked well so far as the recovery of germanium was concerned, yet the yield of gallium from the soluble fractions was very low. It is now known, from work on the arsenates of gallium, shortly to be published, that the loss was undoubtedly due to the presence of arsenic acid: all the arsenic in the ore was concentrated by this method as arsenic acid in the soluble fractions, and it has since been shown that this acid peptises gallium arsenate under certain conditions. The presence of the large amounts of copper and iron also made the recovery of gallium a tedious process.

Keil (*Z. anorg. Chem.*, 1926, **152**, 103) decomposed the ore with nitric–sulphuric acid mixture, distilled off the germanium tetrachloride, and concentrated the gallium as ferrocyanide. Keil and Berg (*ibid.*, 1932, **209**, 383) modified the process by extracting gallium and ferric chlorides with ether saturated with hydrochloric acid.

The foregoing methods are not entirely satisfactory because they can deal with only small quantities of ore at a time. Patnode and Work (*Ind. Eng. Chem.*, 1935, **23**, 204) have described a semi-large-scale method for recovering germanium, but they have not yet described the recovery of gallium from the residues. Finally, Foster, Johnson, and Krauss (*J. Amer. Chem. Soc.*, 1935, **57**, 1828, 1832) distilled germanium monosulphide in ammonia gas and extracted gallium from the residue by methods similar to those described by earlier workers.

All these methods require for the extraction of gallium an acid decomposition of the ore or ore residues, and the large amounts of copper, iron, lead, zinc, and other metals go into solution with the gallium. This makes the recovery of gallium tedious. However, since both germanium and gallium form soluble alkali salts, and since the ore is a sulphide ore in which germanium is present probably as thiogermanate, it was expected that both elements would be extracted by alkali digestion. This expectation has been fully realised. The effect of this modification is to concentrate in a single operation both of the rare elements, free from even traces of copper, iron, and zinc, which remain as insoluble sulphides. This simplifies the extraction of both to an enormous degree, because their separation from arsenic and from each other is comparatively simple. Furthermore, the method can be adapted for large-scale use, and even on the laboratory scale it is possible to recover the gallium content of several kg. of ore within a week.

EXPERIMENTAL.

Alkaline Extraction.—1 Kg. of crushed germanite (180-mesh) is slowly dusted into an iron basin containing sodium hydroxide (500—600 g.) dissolved in its own weight of water; a vigorous reaction takes place, and it is best to cool the caustic liquor before adding the ore. By being thus dusted in, the ore is completely wetted and does not then tend to stick to the bottom of the basin. The mixture is heated over an air-bath, and the water allowed to evaporate. As the mass becomes pasty, it should be stirred to prevent caking. In the course of an hour the mass dries, and it is then scraped into about 1 l. of water. It is essential to dilute it immediately; otherwise, oxidation occurs, giving colloidal sulphides difficult to filter. The hot liquid is filtered through asbestos or paper (Whatman No. 5), and washed with hot water until the washings are pale yellow. The total volume at this stage is about 4 l. Sometimes, when the filtrate is allowed to cool before washing is commenced, white needle-like crystals separate, but they dissolve in the washings. These crystals gave all the tests quoted by Gutman for sodium trioxysulpharsenate (Mellor, "Comprehensive Treatise on Inorganic and Theoretical Chemistry," Vol. IX, 329). The insoluble ore residue is discarded, but it is necessary to guard against the risk of fire because the moist and finely divided material oxidises rapidly with great evolution of heat.

The filtrate contains germanium, arsenic, and a little molybdenum as thio-salts and gallium in anionic condition. Though germanium sulphide is not usually precipitated from neutral solution, it is not possible to separate the gallium and arsenic by neutralisation, for the arsenic sulphide carries down much of the germanium with it: in addition, the solution is highly coloured and neutralisation is difficult. The best plan at this stage is to oxidise the sulphides.

The liquid is partly neutralised with sulphuric acid, and then made acid with nitric acid. The reaction with nitric acid is vigorous and the liquid boils; the precipitated sulphides and hydroxides gradually disappear and give place to a brownish scum of arsenious sulphide and sulphur, which is filtered off.

From the filtrate, gallium is completely precipitated by neutralisation. At first, methyl-red was used as indicator, but it was then found that one-third of the gallium remained in solution. The reason for this remained obscure until gallium arsenate was studied, and the results of this investigation, shortly to be communicated, have shown that ammonium arsenate is able to peptise gallium arsenate at p_H values greater than 3: at this p_H value, however, gallium arsenate is almost quantitatively precipitated. The most suitable indicator for use was found to be benzylanilineazobenzenesulphonic acid. With the gallium at this stage is co-precipitated about two-thirds of the germanium as hydrated oxide, and this fact makes filtration easier. The remainder of the germanium is recovered, again as hydrated oxide, by adding to the filtrate 10% by vol. of concentrated ammonia. A trace still remains, however, and this is recovered by adding magnesium sulphate to the filtrate (Muller, *J. Amer. Chem. Soc.*, 1922, **44**, 2496).

The germanium–gallium precipitate is next dehydrated by being heated to fuming with sulphuric acid: dehydrated germanium dioxide is almost insoluble in acids (Pugh, J., 1929, 1537) and is removed by filtration. Thus, about 90% of the germanium in the ore is concentrated in two fractions as oxide and hydrated oxide. Both fractions are almost free from arsenic, which is a great advantage, and pure germanium dioxide is obtained from them by simple distillation with hydrochloric acid, as described by Pugh (*loc. cit.*). There is no need for elaboration on this point because it has been amply described in the literature.

All the gallium is now in solution as sulphate, together with arsenic acid, a little molybdenum, and traces of germanium, lead, and tungsten. Considerable difficulty was experienced at first in removing the arsenic completely, and this was eventually traced to the presence of molybdenum, which forms rather stable complexes with arsenic acid; hydrogen sulphide in acid solution acts very slowly even after treatment with sulphur dioxide in boiling solution. Eventually, a simple and effective method was evolved. The solution is made alkaline, treated with excess of sodium sulphide, and acidified with hydrochloric acid. Arsenic, tungsten, and molybdenum are completely precipitated. The precipitate, however, adsorbs a trace of gallium, which is recovered by boiling with hydrochloric acid.

The filtrate now contains mere traces of germanium, lead, and molybdenum and the small amount of aluminium phosphate in the original ore. For removal of impurities from gallium solutions it is necessary frequently to concentrate the gallium by precipitation; the use of ammonium carbonate as described by Lecoq de Boisbaudran (*Ann. Chim. Phys.*, 1877, **10**, 119) is convenient in that it gives a more granular hydroxide than ammonia.

To remove germanium, the gallium is precipitated with ammonium carbonate and boiled with concentrated hydrochloric acid and a drop of bromine, to oxidise the sulphide; germanium tetrachloride volatilises. It is not possible, however, to remove the last trace of lead. Hydrogen sulphide in acid solution gives no precipitate because the acidity of the solution from hydrolysis of gallium sulphate is too high. The greater part of the lead can be removed by treating the alkaline solution with hydrogen sulphide and keeping it overnight. The last trace of molybdenum sulphide is precipitated when the solution is subsequently made faintly acid. Even so, a trace of lead goes through in colloidal solution and contaminates the crude gallium metal obtained. The isolation of the gallium by electrolysis and its subsequent purification are described in the following paper.

Analysis and Yield.—The sample of ore used in this investigation has given much larger yields of gallium than have ever been reported in the mineral, the highest hitherto being 0·74% (Berg and Keil, *loc. cit.*). All previous methods of analysis, however, have made use of acid to decompose the ore, and it is our opinion that considerable losses of gallium have occurred during its separation from the heavy metals, or, alternatively, that such methods do not extract the total gallium content of the ore. The following method of analysis has proved more satisfactory.

Finely powdered ore (5 g.) and sodium hydroxide (10 g.) are heated to quiet fusion in an iron crucible, and the cooled melt is extracted with water, the residue filtered off, and washed. The filtrate is acidified with hydrochloric acid so that the excess acidity is about 2*N*. The liquid is boiled to ensure complete solution of the gallium and to coagulate arsenic and molybdenum sulphide: there is sufficient sulphide in the fusion extract to remove all the arsenic at this stage. The sulphides are filtered off and the filtrate is neutralised (to methyl-red) with sodium hydroxide. The precipitated gallium hydroxide is evaporated to dryness with hydrochloric acid to volatilise traces of germanium and to dehydrate silicic and tungstic acids. The last traces of lead and molybdenum are removed by treatment with hydrogen sulphide in alkaline and in acid solution, as described above, and the gallium is finally precipitated with cupferron according to the method of Moser and Brukl (*Monatsh.*, 1929, **51**, 327). The germanium content was determined by methods already described (Thomas and Pugh, *loc. cit.*) (Found: Ga, 1·20, 1·20, 1·25; GeO_2, 7·9%). The actual yields per kg. of ore by the extraction process described above were: Ga, 10 g.; GeO_2, 70 g.

The authors thank Prof. J. Smeath Thomas for his kindness in allowing them to use the sample of the mineral.

University of Capetown. [*Received, July 19th*, 1937.]

282. *Gallium. Part III. The Electrodeposition, Purification, and Dissolution of Gallium.*

By F. Sebba and W. Pugh.

Though much work has been published on the electrodeposition of gallium, this has necessarily been accomplished with small amounts of the metal. The problem of dealing with larger amounts, such as are available from germanite, is quite different. Moreover, in spite of the work already published, there is little in the literature to indicate what degree of success may be expected under various conditions. For this reason, the conditions for the successful electrodeposition of quantities of the order of 10 g. of metal have been studied. The metal obtained in this way from germanite contains traces of lead, tin, and platinum, and it is shown that the last traces of these impurities are removed by simple washing with hydrochloric and nitric acids. The behaviour of the metal towards acids has also been studied.

Since Lecoq de Boisbaudran first isolated gallium by electrolysis (*Bull. Soc. chim.*, 1879, **31**, 50), this method has often been used. The earlier workers, Schucht (*Chem. News*, 1880, **41**, 280), Ehrlich (*Chem.-Ztg.*, 1885, **9**, 78), and Kunert (*ibid.*, p. 1826), followed the original method of electrolysing alkaline solutions, but gave only scanty details. Uhler and Browning (*Amer. J. Sci.*, 1916, **42**, 394) also employed alkaline solutions, and found

that the metal is deposited from cold solution in the form of trees, and from warm solution as globules which drop off the cathode.

More recent workers have preferred acid solutions. For instance, Richards and Boyer (*J. Amer. Chem. Soc.*, 1921, **43**, 274) and Richards and Craig (*ibid.*, 1923, **45**, 1157) were able to prepare pure gallium from sulphuric acid solutions provided the concentration of acid did not exceed 0·04*N*; they were chiefly concerned, too, with the separation of zinc and indium impurities. Obviously, this method is not very suitable for dealing with large amounts of gallium which require a considerable concentration of free acid to maintain them in solution. The same applies to Reichel's method (*Z. anal. Chem.*, 1932, **87**, 322), who obtained quantitative yields from ammoniacal solution.

For dealing with amounts of the order of 10 g. at a time, such as were obtained from 1 kg. of germanite in the present work, the most obvious choice was electrolysis of alkaline solutions. Dennis and Bridgman (*J. Amer. Chem. Soc.*, 1918, **40**, 1537) made a few observations on this problem and stated that deposition was slow and that the metal probably contained alkali metal. Our experience is the reverse: current efficiencies of 25—30% are possible with concentrated solutions, and the metal obtained is quite free from sodium, at any rate after an acid wash.

Since so little information is available about the conditions necessary for successful electrodeposition from alkaline solution, our method is given in detail.

With regard to temperature, as Uhler and Browning (*loc. cit.*) have shown, cold solutions give gallium trees, which, although often very beautiful, are troublesome in practice. Fronds fully an inch long are often produced, connected to the cathode by a very thin neck: sooner or later they drop off under their own weight and then dissolve appreciably in the alkaline liquor. In hot solution, on the other hand, the metal melts, and provision must be made for collecting the molten metal and maintaining it permanently cathodic to prevent re-dissolution. Success depends largely on the design of the electrode.

It seems to be agreed that a high current density at the cathode is an advantage; for this reason most workers have used wire or rod.

With regard to the choice of cathode materials, platinum has been used by most workers, although it alloys slightly with gallium. Richards and Boyer (*loc. cit.*) used a gallium electrode for the preparation of the pure metal; in our experience, however, this type of electrode is slow, probably because of its small surface area. The only other cathode material that has been used is a tungsten wire (Willard and Fogg, *Trans. Amer. Electrochem. Soc.*, 1934, **66**, 110).

Experimental.

Nickel electrodes were first tried, but they were not adopted for regular work for the following reasons: A nickel anode is easily attacked by traces of anions which form soluble nickel salts, giving rise to a green deposit of nickel hydroxide in the bath; to avoid this would require prolonged washing of the gallium hydroxide. A nickel cathode has the same tendency as platinum to induce the formation of trees in the cold, and a suitable electrode to collect the molten metal could not be designed because of the difficulty of sealing nickel into glass. Apart from this, however, nickel appears to have some advantage over platinum, for gallium does not seem to alloy with it to the same extent. The surface of the cathode was blackened, but the coating was very adherent and gallium was easily melted off under water acidified with a drop of hydrochloric acid.

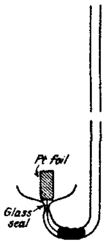
Platinum electrodes were therefore used. The anode was a piece of foil, 20 cm. long and 3 cm. wide, placed round the inside of a 250 c.c. beaker. The cathode (see fig.) was a piece of thick foil, 1·5 cm. by 1 cm., the lower edge of which, wedge-shaped, was sealed into a glass cup blown at one end of a U-tube. Contact was made by a platinum wire through the glass seal to mercury in the U-tube. The glass cup was 3 cm. in diameter, very shallow, but big enough to hold rather more than 10 g. of gallium. It was found advisable to give a thick edge to the platinum foil–glass junction, because the first electrode used was soon corroded at the wire–glass junction. The type described has shown no sign of corrosion after several hundred hours' use.

The molten gallium collected in the cup and remained cathodic; in fact, after a little use the electrode became essentially a gallium electrode of large surface, for the platinum was covered with a layer of gallium. Only the first lot of gallium collected was contaminated with platinum.

The chief advantage of the electrode was that it could be used for quantitative work: the metal was easily washed, dried, and weighed in it.

The gallium from 1 kg. of ore, after removal of impurities as described in the preceding paper, was concentrated by precipitation as hydroxide; this was then dissolved in the minimum of concentrated sodium hydroxide, diluted to 150 c.c., and electrolysed with a current of 1 amp. at 3—4 volts. The resistance of the electrolyte generated sufficient heat to maintain the temperature of the liquid above 30°, the m. p. of the metal. About 6 g. separated during the first 24 hours and 3·5 g. during the next period, but the efficiency then became very low and the recovery of the last 0·5 g. of gallium was tedious. The best plan was to reprecipitate the remaining metal as hydroxide and add it to a subsequent batch. When the aluminium content of the residue had increased appreciably, the remaining gallium was precipitated with cupferron, ignited to oxide, and fused with sodium hydroxide. In this connection it was noticed that the cupferron precipitate carried down with it some aluminium phosphate, which is of importance in relation to the work of Moser and Brukl on the separation of gallium and aluminium (*Monatsh.*, 1929, **51**, 327).

The gallium so obtained was quite free from aluminium. Usually, it was mobile and strongly reflecting, like mercury, but in some cases the metal was greyish and much of it in powder form. This phenomenon appears to be connected with the presence of sulphides, for when these were removed by treatment with peroxide, before electrolysis, globular metal was always produced. The grey metal was easily rendered silvery white and coalescible by one wash with a little nitric acid. The metal which adhered to the electrode was removed by pouring a little warm dilute hydrochloric acid over it, whereupon it immediately became spherical and was easily rubbed off. At no time was the red colloidal gallium solution described by Dennis and Bridgman (*loc. cit.*) observed.



Purification of the Metal.—The crude metal so obtained contained traces of lead, tin, and platinum, which were the only impurities detected spectroscopically. Dennis and Bridgman (*loc. cit.*) suggest that gallium obtained from alkaline solution contains alkali metal, and they find support for this view in the vigorous reaction which occurs when water is added to the metal. This may be true for metal obtained in the tree form, but when it is deposited from warm solution from an otherwise identical bath there is hardly any reaction with water. It would seem that the tree form is more reactive towards water, partly no doubt because of its larger surface area. Recently, Gilfillan and Bent (*J. Amer. Chem. Soc.*, 1934, **56**, 1662) have shown that the solubility of sodium in gallium at its m. p. is only 0·001%.

Various workers have used acids to remove impurities from gallium; Lecoq de Boisbaudran (*Compt. rend.*, 1876, **83**, 638), Richards and Craig (*loc. cit.*), and Dennis and Bridgman (*loc. cit.*) used nitric acid, but Fogg and James (*J. Amer. Chem. Soc.*, 1919, **41**, 949) and Berg and Keil (*Z. anorg. Chem.*, 1932, **209**, 383) used hydrochloric acid. Both acids were used to clean the metal obtained in this work.

All the gallium from the first 5 kg. of ore treated (45 g.) was melted under a little hot water, and an equal volume of concentrated hydrochloric acid added. The metal was rolled backwards and forwards under the acid for 5 minutes, and the acid then carefully washed out. A little concentrated nitric acid was next added; at first there was brisk effervescence and the metal broke up into numerous tiny globules. The reaction gradually abated, and after a few minutes the acid was diluted with water and allowed to react for 10 minutes more, after which it was carefully washed out. Because, after treatment with nitric acid, the metal did not have that clean reflecting surface so characteristic of gallium washed with dilute hydrochloric acid, it was given a final wash with this acid; the tiny globules immediately coalesced.

The action of hydrochloric acid in this respect is striking and has never been exactly described. When a little gallium is melted under water it remains shapeless, has a dull surface, and sticks to glass. This is probably due to a film of oxide on its surface. The addition of a single drop of hydrochloric acid to the water, however, causes the metal immediately to assume a perfectly spherical form. At first there is a brisk evolution of gas but this soon dies down; the metal reacts very slowly with dilute hydrochloric acid. Probably, there is a protective film of gas formed on the surface and, in the absence of edges to facilitate bubble formation, the film remains adherent. The metal so obtained had a perfect reflecting surface.

About 5% of the metal had dissolved during the washing. Tests showed that the wash liquid contained traces of lead, tin, and platinum. The presence of the last was unexpected, for mixtures of acids were not used at any stage. Further tests showed, too, that the whole of the

platinum had been removed. However, as it was naturally expected that some platinum still remained, the total yield (43 g.) was fractionally crystallised as described by Richards and Boyer (*loc. cit.*). Samples of the two extreme fractions and of two middle fractions were then converted into oxide and examined with a Hilger quartz spectrograph. All four samples were identical, and showed no evidence of lead, tin, or platinum. There were four faint lines which could not be identified as gallium lines: **2297·9** [2297·8, Fe(6)], 2624·7 [2625·5, Fe(4)], **2632·6** [**2632·3** Fe(4)], and **2664·7** [Fe(3)]. The nearest line of the most likely impurity, with its intensity as given by Kayser (" Tabelle der Hauptlinien der Linienspektra aller Elemente," Berlin, Springer, 1926), is shown in brackets. It would appear that a spectroscopic trace of iron is the only impurity in the metal, and that fractional crystallisation of the acid-washed metal is quite unnecessary.

Dissolution of Gallium in Acids.—The action of dilute hydrochloric, sulphuric, and nitric acids on gallium is very slow and is probably due to the protective action of a film of gas. This view is supported by the fact that reaction is much faster with oxidising acids.

The action of concentrated sulphuric acid has never been described. There is no action in the cold but, on heating, the metal dissolves vigorously. The gas liberated consists largely of hydrogen sulphide; some sulphur is also formed. In this respect, then, gallium resembles thallium (Ditte, *Ann. Chim. Phys.*, 1891, **19**, 68). After a short time, an insoluble white powder separates and stops further action. If this powder is dissolved by dilution with water, and the remaining metal treated with fresh acid, several g. of metal may be dissolved in an hour, whereas several days are needed by concentrated hydrochloric acid.

Hot concentrated nitric acid is the best solvent and, in this connection, some interesting phenomena have been observed. When the acid is kept just below its b. p there is a continuous and vigorous evolution of gas, giving the impression that the metal is dissolving rapidly. However, about 10 hours are required to dissolve 5 g. Unlike hydrochloric acid, which induces the metal to coalesce, hot nitric acid disperses the metal into large numbers of tiny globules. If the acid is allowed to cool thoroughly, these globules break up into a dark grey powder, and if the acid is then warmed again this powder dissolves very rapidly, leaving some small globules. If this process of alternate warming and cooling is repeated a few times, large amounts of metal may be dissolved in a short time. The mechanism of the reaction is obscure, but it is possible that nitrous acid has much to do with it, because the cold acid in contact with the grey powder is markedly blue.

The authors express their thanks to Prof. S. M. Naude, of the University of Stellenbosch, for taking the spectrograms of the metal, and to Prof. J. Smeath Thomas for the use of the sample of mineral.

University of Cape Town. [*Received, July 19th, 1937.*]

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283. *Force Constants and Molecular Structure. Part II. Ethylene.*

By Harold W. Thompson and J. W. Linnett.

The possibility of studying molecular structure by the determination of force constants is discussed. The principles of this method are outlined, and attention is directed to the shortcomings of some previous treatments of the subject. As a preliminary to the study of a series of related compounds containing C=C and C=O linkages, the relationships with ethylene are examined in detail. The assignment of the nine planar vibration frequencies is discussed and different potential functions are explored. A highly satisfactory function is discovered which has many merits and no serious defects. The force constants of this function are determined, and the precise form of the several vibrations is deduced.

The frequencies of tetradeuteroethylene are estimated.

During the past few years it has been established beyond doubt that in some molecules the linkages between the atoms are of a hybrid nature, showing properties intermediate between those of normal integral bonds of unperturbed structures representable by specific electronic structures. In studying theories of valency and molecular structural problems of this kind,

several properties of a link have been used as a guide to its nature. Such properties are the energy of rupture, the length, and the dipole moment. These quantities, although frequently indicating much, cannot always be used with conviction. Heats of linkage cannot always be determined accurately, and in many cases their estimation may be complicated by subsidiary processes which occur at the moment of cleavage of the molecule; in some cases, moreover, it is only the heat of formation of the entire molecule which is significant for comparative purposes. The estimation of the dipole moment of a link also sometimes involves assumptions regarding the way in which such moments are compounded within the molecule. The estimation of bond length by electron-diffraction methods, though often giving the best and most accurate value, is not always successful by virtue of the widely differing scattering powers of the different atoms.

One other property of a link—its force constant, for both stretching and bending—has the advantage over the heat of rupture in that it portrays the linkage as it actually exists, that is, uncomplicated by dissociation processes. In Part I (this vol., p. 1291), we have shown how variation of the force constants of given linkages in different molecules are closely in agreement with what would be expected on the basis of the other independent data, and it has seemed probable that a systematic examination of more cases of simple polyatomic molecules would be profitable.

Unfortunately, accurate values for the force constants of links in polyatomic molecules are not easily obtained. Early attempts to calculate them regarded the individual molecules as being composed of systems of two groups vibrating as in a diatomic system. This procedure is clearly inadequate. The method now usually employed is to obtain for the assumed molecular model relationships between the normal vibration frequencies and the masses, angles, and force constants. If the vibration frequencies are known from Raman and infra-red spectral measurements, and can be assigned to the different modes, the force constants can then as a rule be deduced. Calculations of this kind have been made by Dennison, Mecke, Lechner, Yates, Kohlrausch, Van Vleck and Cross, Howard and Wilson, Penney and Sutherland, Dennison and Sutherland, Bonner, Rosenthal, Manneback, and others (see Sutherland, *Ann. Reports*, 1936, **33**, 53—64). In Part I (*loc. cit.*) we have shown how the calculations of the force constants of the linkages in carbon suboxide justify the assumption of a hybrid structure.

In this and succeeding papers it is proposed to examine further molecules in the same manner. There are, however, several difficulties and ambiguities in the method which appear to us fundamental, though frequently ignored, and it is necessary first to discuss in some detail the general theory of the method. The difficulties can be conveniently separated into two classes: (1) those relating to the actual mathematical procedure and the assumptions involved in it, (2) those relating to the determination and assignment of the molecular frequencies.

(1) In calculating the expressions which give the frequencies in terms of the masses and force constants, it is necessary first to write down an expression for the potential energy of the vibrating model as a function of the particle displacements. This expression must be consistent with a vibration which is harmonic in character. The kinetic energy is also written down in terms of the masses and particle velocities, infinitesimally small displacements being assumed. Remembering the conditions which express no translation or rotation of the entire molecule in space, and applying Lagrange's equation, we can set up a determinantal equation, the solution of which gives the required normal vibration frequencies. This equation is in the nth power of a quantity μ such that $\nu = \sqrt{\mu}/2\pi$, n being the total number of normal vibrations. If the molecule possesses symmetry elements, and this is usually essential if the problem is to be manageable, the determinantal equation can be factorised according to the different symmetry sub-groups, and thus split into several equations each in lower powers of μ.

The main feature of this procedure is the nature of the potential function assumed, since upon this depends the self-consistency of the calculations in any given case, and consequently the magnitudes of the different force constants involved. Two types of potential function were used initially. The first, representative of what has been called simple valency force field, assumed only forces resulting from changes in bond lengths or in the

angles between the conventional chemical bonds. The second, central force field, assumed forces between pairs of atoms in a molecule regardless of whether a conventional chemical bond joined the two atoms. The use of such potential functions has been summarised by Sutherland (*loc. cit.*). Of the two types, simple valency force field seems in general preferable, but even this is not always satisfactory. This implies the necessity of introducing into the potential function "cross terms" between the different displacement co-ordinates. In any given case the number of theoretically possible cross terms may be large; many of these, however, are negligible, and only those which are at all comparable with the main terms need be considered. The choice, *a priori*, of the proper cross terms to be used may be very difficult. If, for a given molecule, the number of independent constants in the assumed potential function exceeds the number of normal frequencies, it is not possible from the experimental data alone to determine the values of the constants. Provided a sufficiently large number of constants were assumed, a potential function could always be made to reproduce the array of observed frequencies, but this would be no test of the correctness or usefulness of the particular potential function. The only satisfactory test of a given potential function is that it shall reproduce [within the appropriate limits allowed under (2)] a greater number of frequencies than the number of independent constants which the function itself contains. *A priori* we might expect the most reasonable potential function to be that which (i) approaches most nearly to simple valency force field and reproduces all the normal frequencies, (ii) involves only constants to which a precise and visualisable meaning can be attached, and (iii) involves cross terms which by the peculiar circumstances of the particular case might be expected to be the most important.

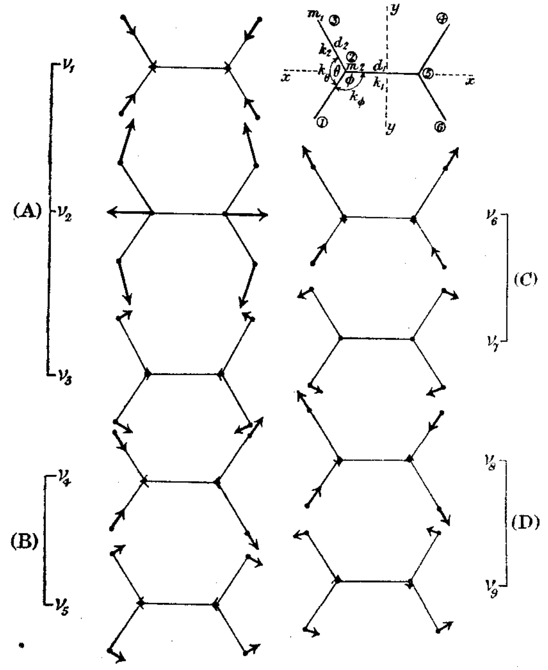
(2) In several previous papers on the present subject, attempts have been made to construct a potential function which would reproduce the observed frequencies to a degree of accuracy which seems to us meaningless. This has usually involved the introduction of a surprisingly large number of constants. Actually, the calculations refer, of course, to a harmonically vibrating model, and the frequencies determined experimentally require correction to infinitesimally small amplitude. It is not possible to predict accurately the magnitude of this correction. If a large number of combination tones can be observed in the infra-red it may occasionally be possible to estimate it. Thus for water (Bonner, *Physical Rev.*, 1934, **46**, 458) it may amount for each normal frequency to *ca.* 5%, and for hydrogen sulphide (Bailey, Thompson, and Hale, *J. Chem. Physics*, 1936, **4**, 625) to *ca.* 5%. With molecules such as carbonyl sulphide involving heavier nuclei, the error may be 1% or less (Bartunek and Barker, *Physical Rev.*, 1935, **48**, 516). Thus a potential function which reproduces the observed frequencies within these limits and has no other defects must be regarded, for the present at least, as satisfactory, and further more complicated potential functions are redundant.

The magnitudes of the observed frequencies for a given molecule may be misleading for a second reason, *viz.*, the possibility of a resonance between two close normal frequencies or a normal frequency and a close overtone level, since the resonance will lead to displacements.

In some of the cases previously studied and referred to above, it has been found impossible to obtain a completely satisfactory mathematical solution to some of the problems. The point which we wish to make from the above considerations is that from a chemical standpoint it may be better to renounce completely "idealistic" and in any case often unrealisable solutions in favour of others which, though not perfect, are nevertheless perfect within the limits of the available knowledge. This seems to us to be the only way of making satisfactory comparisons of force constants in series of related compounds, and it is just this problem which is of chemical interest. A similar view has been expressed by Barnes, Bonner, and Condon (*J. Chem. Physics*, **1936**, **4**, **772**).

In the present paper we discuss calculations of the molecular structure and force constants of ethylene. These will be explained in detail, since they form the basis of similar considerations on the series of molecules ethylene, allene, carbon dioxide, formaldehyde, keten, and carbon suboxide (see Part III). All these molecules are built up from what are usually regarded as C=C and C=O linkages. The case of carbon suboxide has been treated separately in Part I.

1. *The Normal Vibrations of Ethylene.*—There are nine planar normal vibrations of the ethylene molecule. The molecule can be regarded as having two planes of symmetry other than the plane of the molecule; both are perpendicular to the latter, and one contains the C–C bond (plane x/x) and the other (plane y/y) is perpendicular to this bond. The group of nine vibrations splits into four sub-groups: Class A contains three totally symmetrical oscillations (ν_1, ν_2, ν_3), *i.e.*, symmetric to both x/x and y/y. Class B contains two oscillations (ν_4, ν_5) each symmetric to the x/x plane but antisymmetric to the y/y plane. Class C



contains two oscillations (ν_6, ν_7) each symmetric to the y/y plane but antisymmetric to the x/x plane. Class D contains two oscillations (ν_8, ν_9) each antisymmetric to both the x/x and the y/y plane. The magnitudes and assignments of the frequencies have been discussed by Mecke (*Z. physikal. Chem.*, 1932, **17**, *B*, 1), by Sutherland and Dennison (*Proc. Roy. Soc.*, 1935, *A*, **148**, 250), by Teller and Topley (J., 1935, 885), and by Bonner (*J. Amer. Chem. Soc.*, 1936, **58**, 34). The data are summarised in Table I, the last column of which gives the values which we have taken below and which seem most probable.

The three totally symmetric vibrations ν_1, ν_2, ν_3, are intense in the Raman effect; ν_4 and ν_5 should be found as fundamentals in the infra-red; and ν_6 and ν_7 should also appear as fundamentals in the infra-red. In the case of ν_4 and ν_5, the vibration involves a change in

the electric moment parallel to the axis of least inertia, and a marked Q-branch would be expected, whereas the vibrations ν_6 and ν_7 should give a doublet structure ($\perp$ band). On this basis it is possible to assign the several frequencies. The remaining pair (ν_8 and ν_9) should appear in the Raman effect, though probably feebly. There seems to be general

TABLE I.

Frequency.	Mecke.	Sutherland & Dennison.	Teller & Topley.	Bonner.	
ν_1	3019	3019	3019	3019	3019
ν_2	1623	1623	1623	1623	1623
ν_3	1342	1342	1342	1342	1342
ν_4	2988	2988	2990	2988	2988
ν_5	1444	1444	1444	1444	1444
ν_6	3107		3110	3107	3107
ν_7	$\sim$1100		950?	950	950
ν_8	3240		3240	3069	(3069)
ν_9	$\sim$970		1100 or 1160?	950	?

agreement regarding the assignment of all the frequencies except ν_8 and ν_9, although the discussion by Teller and Topley of ν_4 and ν_6, is somewhat confused.* In the earlier Raman measurements of Dickinson, Dillon, and Rasetti (*Physical Rev.*, 1929, **34**, 582), a feeble line at 3240 cm.$^{-1}$ was assigned to ν_8. Bonner, on the other hand, found a feeble line at 3069 and assigned this to ν_8. It seems on the whole probable that 3069 is the more likely value. At the same time, Bonner's measurements were made with liquid ethylene, and selection rules may break down under such conditions. In Bonner's Raman measurements a line observed at 950 is attributed by him to ν_9, but for similar reasons this might really be the frequency ν_7. The frequency ν_9 was taken by Teller and Topley (on the basis of specific-heat data) to be 1100, 1160, or 730. Mecke gave for ν_7 and ν_9 the values 1100 and 970, with uncertain assignment. Taking $\nu_7 = 950$, we should then have $\nu_9 = 1100$. To summarise, therefore, although the assignment of the first seven frequencies seems definite, yet that of the last two is uncertain.

In attempting to calculate the force constants of the linkages, Sutherland and Dennison considered only the "parallel" frequencies ν_1, ν_2, ν_3, ν_4, ν_5. By means of a special type of potential function they were able to reproduce these frequencies fairly well, but they did not deal with the remaining vibrations. They deduced the relationship and adjusted the

$$\nu_4^2 + \nu_5^2 + \frac{m_2 + 2m_1}{m_2} \cdot \frac{\nu_1^2\nu_2^2\nu_3^2}{\nu_4^2\nu_5^2} = \nu_1^2 + \nu_2^2 + \nu_3^2 \quad . \quad . \quad . \quad . \quad (1)$$

observed frequencies slightly so as to fit this equation, on the assumption that the relationship provided a satisfactory proof of the applicability of the particular potential function. This is, however, not satisfactory, since a simple valency force field system (or any field which regards the CH_2 groups as non-interacting units) will provide the above relationship.

Bonner employed a more complicated potential function involving six constants (for planar vibrations) and attempted to determine the values of the constants for each class of vibrations. There are several serious weaknesses in his treatment. First, the cubic equation which he obtained for the frequencies ν_1, ν_2, ν_3 gives imaginary roots for the constants. Bonner attributes this to approximations in the potential function and adopted values for the constants which most nearly fitted the equation. Further, there are other small inconsistencies in the values of the constants obtained for the remaining pairs of frequencies. Finally, Bonner used for ethylene the structure previously suggested by Badger, *viz.*, $\theta = 126°$ ($\widehat{HCH}$) $d_{CH} = 1{\cdot}04 \times 10^{-8}$, and $d_{CC} = 1{\cdot}37 \times 10^{-8}$ cm. It now appears that more accurate values are $\theta = 118°$, $d_{CH} = 1{\cdot}08 \times 10^{-8}$, and $d_{CC} = 1{\cdot}33 \times 10^{-8}$ (see Penney, *Proc. Roy. Soc.*, **1937**, *A*, **158**, **306**).

2. *Calculation of the Force Constants.*—It is profitable first to consider the application to the case of ethylene of simple valency force field. If we take the masses of the hydrogen

* These authors argue from the contour of the infra-red band that $\nu_4 = 3110$ and $\nu_6 = 2990$, but in their subsequent calculations they employ the converse assignment.

atoms to be m_1, of carbon atoms m_2, and the angles $\widehat{HCH}$ and $\widehat{HCC}$ to be θ and ϕ, and the other magnitudes as in the figure, the potential function is

$$2V = 4k_2\Delta_{12}^2 + k_1\Delta_{25}^2 + 4k_\phi\Delta\phi^2 + 2k_\theta\Delta\theta^2$$

k_1 and k_2 are the stretching constants of the C–C and C–H bonds, and k_θ and k_ϕ of the respective angles. Using the general method and remembering that for class A $\Delta\theta = -2\Delta\phi$, for class B $\Delta_{25} = 0$ and $\Delta\theta = -2\Delta\phi$, for classes C and D $\Delta_{25} = 0$ and $\Delta\theta = 0$, we then find,

A.
$$\nu_1^2 + \nu_2^2 + \nu_3^2 = k_2P + k_1R + \frac{(2k_\theta + k_\phi)}{d_2^2}Q \quad . \quad . \quad . \quad . \quad . \quad . \quad (i)$$

$$\nu_1^2\nu_2^2 + \nu_2^2\nu_3^2 + \nu_3^2\nu_1^2 = k_1k_2 \cdot \frac{R}{m_1} + \frac{k_1(2k_\theta + k_\phi)}{d_2^2} \cdot \frac{R}{m_1} + \frac{k_2(2k_\theta + k_\phi)}{d_2^2}S \quad . \quad (ii)$$

$$\nu_1^2\nu_2^2\nu_3^2 = \frac{k_1k_2(2k_\theta + k_\phi)}{d_2^2} \cdot \frac{R}{m_1^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (iii)$$

B.
$$\nu_4^2 + \nu_5^2 = k_2P + \frac{(2k_\theta + k_\phi)}{d_2^2}Q \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (i)$$

$$\nu_4^2\nu_5^2 = \frac{k_2(2k_\theta + k_\phi)}{d_2^2}S \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (ii)$$

C.
$$\nu_6^2 + \nu_7^2 = k_2Q + (k_\phi/d_2^2)P \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (i)$$

$$\nu_6^2\nu_7^2 = (k_2k_\phi/d_2^2)S \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (ii)$$

D.
$$\nu_8^2 + \nu_9^2 = k_2Q + (k_\phi/d_1^2)4R + (k_\phi/d_2^2)P + (k_\phi/d_1d_2)T \quad . \quad . \quad (i)$$

$$\nu_8^2\nu_9^2 = \frac{k_2k_\phi}{d_1^2} \cdot \frac{4R}{m_1} + \frac{k_2k_\phi}{d_2^2}S + \frac{k_2k_\phi}{d_1d_2} \cdot \frac{T}{m_1} \quad . \quad . \quad . \quad . \quad . \quad (ii)$$

in which $P = \{1/m_1 + 2\cos^2 \tfrac{1}{2}\theta/m_2\}$, $Q = \{1/m_1 + 2\sin^2 \tfrac{1}{2}\theta/m_2\}$, $R = 2/m_2$, $S = \{(1/m_1)(1/m_1 + 2/m_2)\}$, $T = 8\cos \tfrac{1}{2}\theta/m_2$.

Substituting in B (i) and B (ii) the values $\nu_4 = 2988$ and $\nu_5 = 1444$, we find $k_2 = 5{\cdot}0 \times 10^5$ or $1{\cdot}18 \times 10^5$ dynes/cm. The latter value is clearly impossible and, taking the former, we find $(2k_\theta + k_\phi) = 1{\cdot}28 \times 10^{-11}$ dyne cm. per radian. Substituting these values in A (i), we find $k_1 = 8{\cdot}95 \times 10^5$, and in A (ii), $k_1 = 9{\cdot}53 \times 10^5$. Thus there is some inconsistency in the equations of groups A and B and this also extends to classes C and D. Taking mean values of the constants, however, *viz.*, $k_1 = 9{\cdot}0 \times 10^5$, $k_2 = 5{\cdot}0 \times 10^5$, $(2k_\theta + k_\phi) = 1{\cdot}28 \times 10^{-11}$, $k_\phi = 0{\cdot}60 \times 10^{-11}$, $k_\theta = 0{\cdot}34 \times 10^{-11}$, and $\theta = 118°$, $d_1 = 1{\cdot}33$, $d_2 = 1{\cdot}08 \times 10^{-8}$, we calculate the frequencies given in Table II.

TABLE II.

Frequency.	Obs.	Calc.	Diff.	Frequency.	Obs.	Calc.	Diff.
ν_1*	3019	3014	− 5	ν_6	3107	3095	−12
ν_2	1623	1723	+100	ν_7	950	955	+ 5
ν_3	1342	1230	−112	ν_8	(3069)	3108	+39
ν_4	2988	2986	− 2	ν_9	950 or 1160 ?	1206	?
ν_5	1444	1445	+ 1				

In view of the uncertainty in the values for ν_8 and ν_9, and the simplicity of the potential function assumed, the other frequencies are strikingly well reproduced with the exception of ν_2 and ν_3. This result indicates that the force field involved is not far removed from that of simple valency force system. This result might have been shown equally well by inserting into the relationship (I) above, the values of the observed frequencies. As already explained, this relationship can be deduced from the potential function of simple valency force field.

It is natural to examine the possible causes of the discrepancy in the values of ν_2 and ν_3.

Presumably it implies the necessity of introducing into the potential function one or more cross terms, and we are led to enquire which of the many possible of such terms are most likely to be concerned. We may proceed in one of two ways. (*a*) We may set up generalised potential functions of different kinds, using a large number of constants, not all of which have a precise and direct significance, and find that function, and the values of its constants, which most satisfactorily reproduces the entire set of frequencies. The disadvantages of this method have been referred to in the introduction. (*b*) We may add to the potential function of simple valency force field only such cross terms as appear to be important from the peculiar nature of the specific problem. This seems to us preferable.

The frequencies ν_2 and ν_3 are found experimentally to be roughly equal in magnitude. Now it is known from a series of examples that the deformation of a methylene radical results in a frequency of *ca.* 1400, and the extension of a C=C bond in one of *ca.* 1600. It would not therefore be surprising if, in the case of ethylene which contains both these structural units, excitation of one oscillation were inevitably to a great extent accompanied by excitation of the other. This means that a change in d_1 is likely to occur simultaneously with a change in θ. We have therefore examined the effect of introducing into the simple function a cross term representing this effect. We write

$$2V = k_1\Delta_{25}^2 + 4k_2\Delta_{12}^2 + 2k_\theta\Delta\theta^2 + 4k_\phi\Delta\phi^2 + 2k_3\Delta_{25}\Delta\theta$$

The three totally symmetric frequencies are then given by:

$$\text{A.}\quad \nu_1^2 + \nu_2^2 + \nu_3^2 = k_2P + k_1R + \frac{(2k_\theta + k_\phi)}{d_2^2}Q - \frac{k_3}{d_2}W \quad . \quad . \quad . \quad . \quad \text{(iv)}$$

$$\nu_1^2\nu_2^2 + \nu_2^2\nu_3^2 + \nu_1^2\nu_3^2 = k_1k_2\frac{R}{m_1} + \frac{k_1(2k_\theta + k_\phi)}{d_2^2}\cdot\frac{R}{m_1} + \frac{k_2(2k_\theta + k_\phi)}{d_2^2}S - \frac{k_2k_3}{d_2}\cdot\frac{W}{m_1} - \frac{k_3^2}{d_2^2}\cdot\frac{R}{m_1} \quad . \quad . \quad . \quad \text{(v)}$$

$$\nu_1^2\nu_2^2\nu_3^2 = \frac{k_1k_2(2k_\theta + k_\phi)}{d_2^2}\cdot\frac{R}{m_1^2} - \frac{k_2k_3^2}{d_2^2}\cdot\frac{R}{m_1^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad \text{(vi)}$$

in which P, Q, R, and S are as before, and $W = 4\sin\frac{1}{2}\theta/m_2$. The equations for the remaining frequencies of all types are as already given, since in all cases $\Delta_{25} = 0$. Examination of the data shows that the values of the constants which are most overall consistent are $k_1 = 9{\cdot}8 \times 10^5$, $k_2 = 5{\cdot}02 \times 10^5$, $k_\theta = 0{\cdot}342 \times 10^{-11}$, $k_\phi = 0{\cdot}594 \times 10^{-11}$, and $k_3 = 0{\cdot}637 \times 10^{-3}$. The values of the frequencies then calculated are shown in Table III.

TABLE III.

Frequency.	Obs.	Calc.	Diff.	Frequency.	Obs.	Calc.	Diff.
ν_1	3019	3018	−1	ν_6	3107	3101	−6
ν_2	1623	1623	0	ν_7	950	950	0
ν_3	1342	1343	+1	ν_8	(3069)	3114	?
ν_4	2988	2993	+5	ν_9	950 or 1160?	1203	?
ν_5	1444	1444	0				

4. *Discussion of the Above Results.*—The agreement found on using the new potential function is remarkable, and since the values calculated are being compared with the observed values (uncorrected for anharmonicity) it is perhaps even accidental. There is, however, no doubt that the treatment given is essentially sound, and some of its merits over those previously attained can be summarised as follows:

(i) The potential function using five independent constants reproduces very closely all seven well-established frequencies, *i.e.*, it is valid for more frequencies than the number of constants it contains.

(ii) All the constants used in the potential function have an exact and obvious physical meaning, and reasons for the relative importance of the only cross term employed can be understood. Further, the magnitude of the cross-term force constant is small compared with those of the principal constants.

(iii) In contrast with the method of Sutherland and Dennison, the present treatment deals not only with the " parallel " vibrations, but also with the perpendicular vibrations.

(iv) The cubic giving ν_1, ν_2, and ν_3 has real roots for the force constants and is thus preferable to that of Bonner.

(v) The type of potential function used can be at once carried over to the case of allene, for which, the same values being taken for the constants, the frequencies of the molecule are reproduced. This is perhaps the greatest success of the entire method, and is explained in Part III.

The only obvious defect of the method and results concerns ν_8 and ν_9. If $\nu_8 = 3069$, the calculated value (3114), though not close, is not seriously in error. The calculated value of ν_9 is 1203. This at once suggests that the observed frequency estimated by Teller and Topley as *ca.* 1160, should be assigned to ν_9. After examining all the evidence, we regard this as probable. A small error in the calculated values of ν_8 and ν_9 might be removed by the insertion of a second small cross term, perhaps of the type $k_4\Delta_{12}\Delta_{23}$.

5. *The Form of the Ethylene Vibrations.*—By using the above method and results, the relative amplitudes of the atomic nuclei in each of the vibrations have been calculated. The results are given in Table IV, and in the figure the vibrations are drawn in accordance with them.

TABLE IV.

Symmetry class.	Frequency.	x_1.	y_1.	x_2.	y_2.
A. $x_1 = x_3 = -x_4 = -x_6$; $y_1 = -y_3 = -y_4 = y_6$; $x_2 = -x_5$; $y_2 = y_5 = 0$	ν_1	+1·0	+1·63	−0·24	0
	ν_2	+1·0	−3·62	−3·48	0
	ν_3	+1·0	−0·51	+0·12	0
B. $x_1 = x_3 = x_4 = x_6$; $y_1 = -y_3 = y_4 = -y_6$; $x_2 = x_5$; $y_2 = y_5 = 0$	ν_4	+1·0	+1·59	−0·17	0
	ν_5	+1·0	−0·73	−0·17	0
C. $x_1 = -x_3 = x_4 = -x_6$; $y_1 = y_3 = y_4 = y_6$; $x_2 = x_5 = 0$; $y_2 = y_5$	ν_6	+1·0	+1·69	0	−0·28
	ν_7	+1·0	−0·51	0	+0·085
D. $y_1 = y_3 = -y_4 = -y_6$; $x_1 = -x_3 = -x_4 = x_6$; $x_2 = x_5 = 0$; $y_2 = -y_5$	ν_8	+1·0	+1·79	0	−0·32
	ν_9	+1·0	−0·23	0	+0·305

Using these values of the relative amplitudes, we can now calculate the percentage of the energy of each particular vibrational quantum which is associated with each term of the potential function. An interesting result is found with the three totally symmetric vibrations ν_1, ν_2, ν_3. Whereas with the vibration $\nu_1 = 3018$ over 95% of the energy is located in the $k_2\Delta_{12}^2$ term, *i.e.*, in the C–H bond, in the case of $\nu_2 = 1623$ and $\nu_3 = 1343$, the localisation of the energy into one particular term, though noticeable, is less pronounced. For the 1623 vibration, there is still a preponderance of energy (*ca.* 80%) in the term corresponding to the stretching of the C=C bond, and similarly for the 1343 vibration in the term corresponding to the deformation of the CH_2 group. It is nevertheless seen that with ν_2 and ν_3 the individuality of the vibration is less definite. This is significant in the light of the previous discussion of the cross term.

6. *The Frequencies of Tetradeuteroethylene.*—The success of the above treatment appears to justify a calculation of the nine planar frequencies of tetradeuteroethylene. In this case, however, the heavier deuterium atoms lead to a decrease in the deformation frequency of the CH_2 group, whereas that of the C=C bond is unaffected. Thus, it may be that the interaction previously referred to is less prominent, *i.e.*, k_3 is smaller than in the case of ethylene. In Table V are given (i) the frequencies calculated on simple valency force field with $k_3 = 0$, $k_1 = 9{\cdot}8 \times 10^5$, $k_2 = 5{\cdot}02 \times 10^5$, $k_\theta = 0{\cdot}342 \times 10^{-11}$, $k_\phi = 0{\cdot}594 \times 10^{-11}$; (ii) the frequencies calculated with $k_3 = 0{\cdot}637 \times 10^{-8}$, and (iii) the values suggested recently by Manneback and Verleysen (*Nature*, 1936, **138**, 367).

The values to be expected should then lie between the limits given by (i) and (ii). It is

TABLE V.

Frequency.	(i).	(ii).	(iii).	Frequency.	(i).	(ii).	(iii).
ν_1	2166	2160	2283·9	ν_6	2291	2291	2308·0
ν_2	1780	1686	1428·8	ν_7	742	742	758·3
ν_3	866	902	1008·9	ν_8	2323	2323	2325·0
ν_4	2101	2101	2152·5	ν_9	1016	1016	678·1
ν_5	1187	1187	1072·8				

seen that these values differ noticeably from those given by Manneback and Verleysen. It would be valuable to have experimental data on this point. In any case, however, we cannot attach any importance to the accuracy attempted by Manneback and Verleysen.

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284. *Force Constants and Molecular Structure. Part III. Molecules containing* C=O *and* C=C *Linkages.*

By H. W. THOMPSON and J. W. LINNETT.

The force constants of the linkages and angles in a series of molecules each built up from C–H, C–O, and C–C bonds are calculated from the known vibration frequencies. The form of the potential-energy function applicable in each case is discussed in detail. The molecules studied include ethylene, allene, formaldehyde, keten, carbon dioxide, and carbon suboxide. The results are correlated with structural properties such as the phenomenon of resonance (mesomerism) and with electronic drifts. The geometric form of the different vibrations is deduced. The relationship between force constant and bond length is discussed.

IN Part II (preceding paper) the significance of a knowledge of force constants in determining molecular structure was discussed. The general methods for the determination of the force constants of individual linkages in polyatomic molecules were outlined, and attention was drawn to various ambiguities in previous papers on this subject. In the present paper, the force constants of the linkages in a series of molecules containing bonds conventionally regarded as C–H, C=C, and C=O are calculated from the known molecular vibration frequencies. These molecules are carbon dioxide, ethylene, formaldehyde, allene, keten, and carbon suboxide. The discussion of such a series of molecules has the advantage that the particular type of molecular model must be retained essentially throughout the series. In this way any marked alteration of the force constant of a given linkage in different compounds will be most easily detectable.

The case of carbon suboxide has already been discussed in Part I (this vol., p. 1291), and that of ethylene in Part II (*loc. cit.*), and in these cases the mathematical method was explained in some detail. For this reason it is necessary here only to summarise the essential results of the calculations. It will be convenient first to discuss each molecule individually, and later to consider all the resulting data together.

1. *Ethylene.*—Suppose the masses of the hydrogen atoms are m_1, of the carbon m_2, and the angles $\widehat{HCH}$ and $\widehat{HCC}$ are θ and ϕ. By assuming a potential function of the form

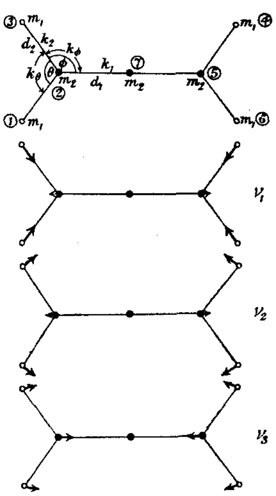
$$2V = 4k_2\Delta_{12}^2 + k_1\Delta_{25}^2 + 4k_\phi\Delta\phi^2 + 2k_\theta\Delta\theta^2 + 2k_3\Delta_{25}\Delta\theta$$

it was possible to interpret very well all the nine planar frequencies. In this expression k_1 represents the stretching constant of the carbon–carbon bond, k_2 that of the carbon–hydrogen bond, and k_θ and k_ϕ the bending constants of the appropriate angles; k_3 could be imagined as arising from the interaction of the carbon–carbon bond with the $\widehat{HCH}$ angle, since the frequency of the vibration largely determined by a stretching of the C–C bond is roughly equal in magnitude to that frequency which is largely determined by a change in the angle θ.

The values of the five constants in the above potential function which most adequately reproduce the molecular vibration frequencies are $k_1 = 9{\cdot}8 \times 10^5$, $k_2 = 5{\cdot}02 \times 10^5$, $k_3 = 0{\cdot}637 \times 10^{-3}$, $k_\theta = 0{\cdot}342 \times 10^{-11}$, $k_\phi = 0{\cdot}594 \times 10^{-11}$.

2. *Allene.*—Suppose that the masses of the atoms are as above, and the other magnitudes as in Fig. 1. No measurements are recorded on the link lengths and angles of this molecule, which are therefore assumed to be the same as the corresponding ones of ethylene. There are 11 planar normal vibrations of this molecule, three of which are totally symmetric. Experimental determination of the frequencies has been carried out by Bourguel and Piaux (*Bull. Soc. chim.*, 1932, **51**, 1041), and by Kopper and Pongratz (*Wien. Ber.*, 1932, **141**, IIb, 840), both investigations dealing with the Raman spectrum. The frequencies found by the former authors were 1073 (strong), 1438 (medium), 3000 (strong), and 3072 (medium), and by the latter authors 1074 (strong), 1435 (medium), 2995 (strong), and 3060 (medium). The infra-red spectrum does not appear to have been measured. The three totally symmetrical oscillations will be most intense in the Raman spectrum and may therefore be taken as 1074, 1436, and 2997. For our present purpose we shall deal only with these frequencies; it may be profitable later to discuss the remaining types.

Fig. 1.



Allene.

Kopper and Pongratz, regarding the molecules as a triatomic system $H_2C{-}C{-}CH_2$, estimated the carbon–carbon force constant. This procedure is obviously unsatisfactory.

The potential function of simple valency force field being assumed, *i.e.*,

$$2V = 4k_2\Delta_{12}^2 + 2k_1\Delta_{27}^2 + 2k_\theta\Delta\theta^2 + 4k_\phi\Delta\phi^2$$

the resulting equations for the three totally symmetric frequencies involve three independent constants k_2, k_1, and $(2k_\theta + k_\phi)$. If the three frequencies have the values given above, no set of values for the three constants will give an adequate agreement. The discrepancies are precisely parallel in nature to those found in the application of simple valency force field to ethylene. If we insert into the equations for allene the values for the C–H bond constant previously found for ethylene, and attempt to calculate for allene k_1 and $(2k_\theta + k_\phi)$, no real values are obtained.

This means that "cross terms" must be introduced into the potential function, and the one which at once suggested itself was that found to be so relevant with ethylene, *viz.*, $k_3\Delta_{CC}\Delta\theta$. In allene, however, it is not impossible that we ought also to introduce a second cross term of the form $k_4\Delta_{27}\Delta_{75}$, arising from an interaction between the two C–C bonds. Such a cross term has been found to be important in the case of carbon dioxide. The potential function can then be written:

$$2V = 2k_1\Delta_{27}^2 + 4k_2\Delta_{12}^2 + 2k_\theta\Delta\theta^2 + 4k_\phi\Delta\phi^2 + 2k_3\Delta_{27}\Delta\theta + k_4\Delta_{27}\Delta_{75}$$

The equations for the frequencies are then found to be:

$$\nu_1^2 + \nu_2^2 + \nu_3^2 = (k_1 + \tfrac{1}{2}k_4)[A] + k_2[B] + \frac{(2k_\theta + k_\phi)}{d_2^2}[C] - \frac{k_3}{d_2}[D] \quad . \quad . \quad (1)$$

$$\nu_1^2\nu_2^2 + \nu_2^2\nu_3^2 + \nu_3^2\nu_1^2 = (k_1 + \tfrac{1}{2}k_4)k_2\left[\frac{A}{m_1}\right] + (k_1 + \tfrac{1}{2}k_4)\frac{(2k_\theta + k_\phi)}{d_2^2}\left[\frac{A}{m_1}\right] + k_2\frac{(2k_\theta + k_\phi)}{d_2^2}[E] - k_2\frac{k_3}{d_2}\left[\frac{D}{m_1}\right] - \frac{k_3^2}{d_2^2}\left[\frac{A}{2m_1}\right] \quad . \quad . \quad (2)$$

$$\nu_1^2\nu_2^2\nu_3^2 = k_2(k_1 + \tfrac{1}{2}k_4)\frac{(2k_\theta + k_\phi)}{d_2^2}\left[\frac{A}{m_1^2}\right] - \frac{k_2k_3^2}{d_2^2}\left[\frac{A}{2m_1^2}\right] \quad . \quad . \quad . \quad (3)$$

in which $A = 1/m_2$, $B = 1/m_1 + 2\cos^2\frac{1}{2}\theta/m_2$, $C = 1/m_1 + 2\sin^2\frac{1}{2}\theta/m_2$, $D = 2\sin\frac{1}{2}\theta/m_2$, $E = (1/m_1 + 2/m_2)/m_1$.

The above equations involve only four constants, since k_1 and k_4 always occur as a sum $(k_1 + \frac{1}{2}k_4)$, and k_θ and k_ϕ as the sum $(2k_\theta + k_\phi)$. These four independent constants have to reproduce the values of three frequencies, and from the values of the three frequencies given above alone it would of course be impossible to calculate the constants. There is here, however, no case of the type to which we have drawn attention in the previous paper, *i.e.*, a potential function involving more constants than the number of frequencies. Actually, in order to calculate all the 11 planar vibration frequencies, using a potential function of the present form, we should require values for seven constants k_1, k_2, k_θ, k_ϕ, k_3, k_4, and a bending constant of the C–C–C angle. We are not at present concerned with vibrations other than the three totally symmetric ones.

The value of the present procedure is as follows. We should expect to be able to use the force constants derived for ethylene in the case of allene. Taking $k_1 = 9{\cdot}8 \times 10^5$, $k_2 = 5{\cdot}02 \times 10^5$, $(2k_\theta + k_\phi) = 1{\cdot}279 \times 10^{-11}$, and $k_3 = 0{\cdot}637 \times 10^{-3}$, and assuming first that $k_4 = 0$, we find values for the frequencies ν_1, ν_2, and ν_3, of 3003, 1459, and 1069. The errors are + 6, + 23, − 5. This agreement is very striking. It is possible that the discrepancies arise from anharmonic properties, but if it is desired to obtain exact agreement, this can be achieved by taking for the constant $(k_1 + \frac{1}{2}k_4) = 9{\cdot}73 \times 10^5$, $k_2 = 5{\cdot}0 \times 10^5$, $(2k_\theta + k_\phi) = 1{\cdot}273 \times 10^{-11}$, and $k_3 = 0{\cdot}821 \times 10^{-3}$. The values of the frequencies then found are 2997, 1436, and 1073. Kohlrausch, regarding the molecule as a triatomic system, gives for k_1 a value $9{\cdot}5 \times 10^5$.

Two points are thus established: (i) The value of k_4 is probably zero. The calculated value of $(k_1 + \frac{1}{2}k_4)$ is so close to that of k_1 in ethylene as to suggest that there is no detectable alteration in passing from one compound to the other. If the change is assumed to be real and k_1 to be $9{\cdot}8 \times 10^5$, k_4 would have a value $- 0{\cdot}14 \times 10^5$. In any case it is unlikely that k_4 can be very appreciable, since the above deduced value of $(k_1 + \frac{1}{2}k_4)$ could then only result from an almost exactly compensating change in k_1. *A priori*, such an exact balancing is unlikely. (ii) It is obvious that in passing from ethylene to allene, k_1, k_2, and $(2k_\theta + k_\phi)$ remain almost unchanged. The change in k_3 is very reasonable and not unexpected from the nature of the effect with which this constant deals.

The values of the constants deduced above for allene being used, the relative atomic displacements of each of the three totally symmetrical vibrations are given in Table I, and the vibrations are seen in Fig. 1.

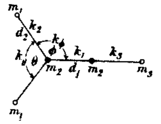
TABLE I.

Totally symmetric.	Frequency.	x_1.	y_1.	x_2.
$x_1 = x_3 = -x_4 = -x_6$	2997 (ν_1)	+1·0	+1·614	−0·195
$y_1 = -y_3 = -y_4 = y_6$	1436 (ν_2)	+1·0	−0·82	−0·274
$y_2 = y_5 = 0$	1073 (ν_3)	+1·0	−0·12	+0·69
$x_2 = -x_5$				
$x_7 = y_7 = 0$				

If we now calculate the energy corresponding to each of the terms in the potential function, it is found that for the 2997 vibration over 98% of the energy is associated with the term representing the change in length of the C–H bond; with the 1436 vibration, however, this isolation of the energy into one term of the potential function is less marked, and although primarily associated with the deformation of the methylene group, some of the energy passes into the term representing change in the length of the carbon–carbon bond; for the 1073 vibration there is again some partitioning of the energy between the same terms as for the 1436 vibration, but the bulk of the energy is in this case in the carbon–carbon stretching term. This result seems worthy of mention, since, although it is not surprising that the methylene group deformation frequency remains as in ethylene (*ca.* 1400), we might have expected the vibration of the C–C link to have the higher of the pair of values.

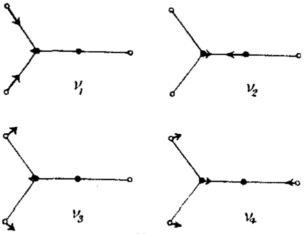
3. *Keten.*—The masses of the hydrogen and carbon atoms being as before, let that of oxygen be m_3 and the other magnitudes as in Fig. 2. No experimental data are available regarding the precise form of the molecule, and we shall assume as for ethylene $\theta = 118°$, $d_2 = 1{\cdot}08$ A. There are good reasons for believing these values to be close to the real ones.

FIG. 2.



The molecule has two symmetry elements, one the plane of the molecule, and the other a two-fold rotation axis containing the atoms 2, 4, 5. There are nine normal vibrations, seven of which are planar, and of the planar group four (ν_1, ν_2, ν_3, ν_4) are symmetrical, and three (ν_5, ν_6, ν_7) antisymmetrical to this rotation axis.

The only experimental measurements of the frequencies have been made by Kopper (*Z. physikal. Chem.*, 1936, **34**, *B*, 396). From his data on the Raman effect it seems certain that ν_1, ν_2, ν_3, and ν_4 have the values 2952, 2049, 1344, and 1130; ν_1, ν_3, and ν_4 appear intense in the Raman effect, and although ν_2 is relatively feeble, it is the only frequency in the region of 2000, where it is certain that the frequency determined largely by a vibration of the C–O bond must lie. This assignment agrees with that suggested by Kopper. The assignment of the antisymmetric vibrations is not possible, and infra-red data are desirable.



Keten.

As with ethylene and allene, the simple valency force field system is inadequate, and we have at once applied a potential function of the following form :

$$2V = k_1\Delta_{24}^2 + 2k_2\Delta_{12}^2 + k_3\Delta_{45}^2 + k_\theta\Delta\theta^2 + 2k_\phi\Delta\phi^2 + k_4\Delta_{24}\Delta\theta + k_5\Delta_{24}\Delta_{45}$$

In this function k_1, k_2, k_3 represent the force constants for the stretching of the C–C, C–H, and C–O bonds, and k_θ and k_ϕ the bending constants of the angles θ and ϕ; k_4 represents the cross-term interaction constant found to be so serviceable in the cases of ethylene and allene. The only addition is k_5, which introduces a cross term to represent interaction between the C–C and C–O bonds. This is to be expected on the same general grounds as the cross term involving k_4.

Using the above potential function, we obtain :

$$\nu_1^2 + \nu_2^2 + \nu_3^2 + \nu_4^2 = k_1[A] + k_2[B] + k_3[C] + \frac{2k_\theta + k_\phi}{d_2^2}[D] - k_5\left[\frac{A}{2}\right] - \frac{k_4}{d_2}[E] \quad . \quad (1)$$

$$\nu_1^2\nu_2^2 + \nu_2^2\nu_3^2 + \nu_3^2\nu_4^2 + \nu_1^2\nu_3^2 + \nu_1^2\nu_4^2 + \nu_2^2\nu_4^2 = k_1k_3[F] + k_2k_3[BC] + \frac{k_3(2k_\theta + k_\phi)}{d_2^2}[DC] +$$
$$k_1k_2[G] + \frac{k_1(2k_\theta + k_\phi)}{d_2^2}[H] + \frac{k_2(2k_\theta + k_\phi)}{d_2^2}[J] - \frac{k_3k_4}{d_2}[CE] - \frac{k_2k_4}{d_2}\left[\frac{E}{m_1}\right] - \frac{1}{2}\cdot\frac{k_4^2}{d_2^2}[H] -$$
$$k_2k_5\left[\frac{B}{m_2}\right] - \frac{k_5(2k_\theta + k_\phi)}{d_2^2}\left[\frac{D}{m_2}\right] - k_5^2\left[\frac{F}{4}\right] + \frac{k_5k_4}{d^2}\left[\frac{E}{2m_2}\right] \quad . \quad . \quad (2)$$

$$\nu_1^2\nu_2^2\nu_3^2 + \nu_1^2\nu_2^2\nu_4^2 + v_2^2\nu_3^2\nu_4^2 + \nu_1^2\nu_3^2\nu^2_4 = k_1k_2k_3\left[\frac{C}{m_1m_2} + \frac{B}{m_2m_3}\right] +$$
$$\frac{k_1k_3(2k_\theta + k_\phi)}{d_2^2}\left[\frac{C}{m_1m_2} + \frac{D}{m_2m_3}\right] + \frac{k_2k_3(2k_\theta + k_\phi)}{d_2^2}[JC] + \frac{k_1k_2(2k_\theta + k_\phi)}{d_2^2}[K] - \frac{k_2k_3k_4}{d_2}\left[\frac{EC}{m_1}\right] -$$
$$\frac{k_3k_4^2}{2d_2^2}\left[\frac{C}{m_1m_2} + \frac{D}{m_2m_3}\right] - \frac{k_2k_4^2}{d_2^2}\left[\frac{K}{2}\right] - \frac{k_2k_5(2k_\theta + k_\phi)}{d_2^2}\left[\frac{J}{m_2}\right] - \frac{1}{4}k_2k_5^2\left[\frac{C}{m_1m_2} + \frac{B}{m_2m_3}\right] -$$
$$\frac{k_5^2(2k_\theta + k_\phi)}{4d_2^2}\left[\frac{C}{m_1m_2} + \frac{D}{m_2m_3}\right] + \frac{k_2k_5k_4}{d_2}\left[\frac{E}{2m_1m_2}\right] \quad . \quad . \quad (3)$$

$$\nu_1^2\nu_2^2\nu_3^2\nu_4^2 = \left\{\frac{k_1k_2k_3(2k_\theta + k_\phi)}{d_2^2} - \frac{1}{4}\cdot\frac{k_2k_5^2(2k_\theta + k_\phi)}{d_2^2} - \frac{1}{2}\frac{k_2k_3k_4^2}{d_2^2}\right\}\left\{L\right\} \quad . \quad . \quad (4)$$

in which: $A = 2/m_2$, $B = 1/m_1 + 2\cos^2\frac{1}{2}\theta/m_2$, $C = 1/m_2 + 1/m_3$, $D = 1/m_1 + 2\sin^2\frac{1}{2}\theta/m_2$, $E = 2\sin\frac{1}{2}\theta/m_2$, $F = 1/m_2^2 + 2/m_2m_3$, $G = 2/m_1m_2 + 2\cos^2\frac{1}{2}\theta/m_2^2$, $H = 2/m_1m_2 + 2\sin^2\frac{1}{2}\theta/m_2^2$, $J = 1/m_1^2 + 2/m_1m_2$, $K = 2/m_1m_2^2 + 2/m_1^2m_2$, $L = (2m_1 + 2m_2 + m_3)/m_1^2m_2^2m_3$.

We thus have four frequencies and six independent constants. Were it not for the guidance provided by the considerations with ethylene and allene, the problem would be insoluble. We can, however, see that the value of k_2 determines ν_1, and hardly affects the values of the remaining frequencies. The value of k_2 which is most suitable is $4{\cdot}85 \times 10^5$. The results with ethylene and allene suggest that suitable values for k_1 and k_4 are $9{\cdot}8 \times 10^5$ and $0{\cdot}8 \times 10^{-3}$. Taking these values, we then find $k_3 = 12{\cdot}3 \times 10^5$, $(2k_\theta + k_\phi) = 1{\cdot}12 \times 10^{-11}$, $k_5 = 1{\cdot}0 \times 10^5$. Small errors in the values assumed for k_1 and k_4 do not at all seriously affect the deduced values for the other three constants, and the success of the method lies, as will be seen, in the remarkable self-consistency of all the results subsequently obtained. With the values $k_2 = 4{\cdot}85 \times 10^5$, $k_1 = 9{\cdot}8 \times 10^5$, $k_3 = 12{\cdot}3 \times 10^5$, $(2k_\theta + k_\phi) = 1{\cdot}12 \times 10^{-11}$, $k_4 = 0{\cdot}8 \times 10^{-3}$ and $k_5 = 1{\cdot}0 \times 10^5$, the calculated frequencies are $\nu_1 = 2954$, $\nu_2 = 2048$, $\nu_3 = 1349$, $\nu_4 = 1123$, the errors being + 2, − 1, + 5, and − 7.

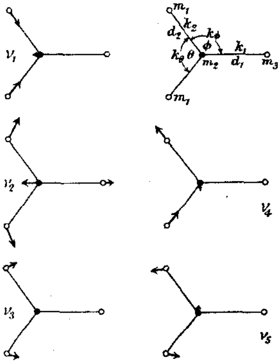
The relative amplitudes of the masses in the several vibrations can now be evaluated as in the previous cases. The values are given in Table II. In Fig. 2 the vibrations are drawn to scale.

TABLE II.

Symmetric.	Frequency.	x_1.	y_1.	x_2.	x_4.	x_5.
$x_1 = x_3$, $y_1 = -y_3$	2954	+1·0	+1·64	−0·2	+0·04	−0·01
$y_2 = y_4 = y_5 = 0$	2048	+1·0	+1·71	+2·88	−7·42	+3·28
	1349	+1·0	−0·81	−0·28	−0·03	+0·10
	1123	+1·0	−0·26	+0·49	−0·04	−0·46

If the energies corresponding to the various terms of the potential function are now evaluated for each vibration, the following results emerge. In the 2954 vibration, more than 96% of the energy is located in the C–H bonds; in the 2048 vibration, *ca.* 55% of the energy is in the C–O linkage, and *ca.* 40% in the C–C linkage, *i.e.*, nearly all the quantum is collected into these two bonds; in the 1349 vibration *ca.* 75% of the energy is in the deformation of the $\widehat{HCH}$ angle, the remainder being distributed largely between the C–O and C–C linkages; in the 1123 vibration 40% of the energy is in the C–C bond and *ca.* 25% in each of the terms representing a stretching of the C–O bond and the deformation of the $\widehat{HCH}$ angle. In each of the last three vibrations there is less than 1% of the energy in the C–H bonds, in agreement with the fact that the value of the C–H bond force constant has little influence upon these frequencies. While the 1349 vibration can be regarded as largely confined to a deformation of the methylene group, the vibrations 2049 and 1123 are much less completely associated with the vibration of a particular bond or the deformation of a particular angle.

FIG. 3.



Formaldehyde.

4. *Formaldehyde.*—With atomic masses as before, let the angles $\widehat{HCH}$ and $\widehat{HCO}$ be θ and ϕ, as in Fig. 3. There are six normal vibration frequencies of this molecule, five of which are planar. Of the planar frequencies

three are symmetrical and two antisymmetrical to the symmetry axis. Two matters call for immediate attention : first, the experimental data relating to the molecular shape, and secondly, the experimental determination and assignment of the several normal frequencies. The shape of the molecule has been discussed by Dieke and Kistiakowsky (*Physical Rev.*, 1934, **45**, 4), who, from an analysis of the ultra-violet absorption bands, determined the moments of inertia in the ground state. The values of these moments of inertia were 24·33 $\times 10^{-40}$, 21·39 $\times 10^{-40}$, and 2·941 $\times 10^{-40}$ g.-cm.^{2}. Three independent quantities are necessary to define the shape of the molecule completely, *viz.*, d_1, d_2, and θ. Dieke and Kistiakowsky assumed $\theta = 110°$, whence $d_2 = 1·15$ and $d_1 = 1·19$ A. In the light of more recent knowledge with related molecules, these values may need revision. Whatever the value of d_1, we might expect d_2 to be lower and θ rather higher than the values used by Dieke and Kistiakowsky. With the values for the moments of inertia given above, different values of θ give the values of d_2 and d_1 shown in Table III.

TABLE III.

Temp.	110°	112°	114°	116°	118°	120°
d_2	1·15	1·136	1·122	1·109	1·097	1·086
d_1	1·185	1·191	1·197	1·203	1·208	1·213

After considering all the evidence, it seems best to assume $\theta = 114°$. This gives $d_2 = 1·122$ and $d_1 = 1·197$ A. This value of d_1 agrees within the limits of error with the electron-diffraction data (Brockway, *Rev. Mod. Phys.*, 1936, **8**, 261), which suggest $1·15 \pm 0·05$ A. Further justification for the correctness of the magnitudes chosen will become apparent later.

The experimental determinations of the vibration frequencies of formaldehyde are not very satisfactory. The earlier data are summarised by Sponer (" Molekülspektren," Vol. I, p. 86) and by Mecke (" Hand- und Jahrbuch der Chem. Physik," Vol. 9, ii, 377), but these were largely based on Raman spectral measurements with formaldehyde solution. Undoubtedly more accurate values are to be taken from the measurements of Nielsen (*Physical Rev.*, 1934, **46**, 117) in the infra-red. The molecule is an asymmetric top with $A \neq B \neq C$ and $A \cong B/_{10}$, according to Dennison's nomenclature (*Rev. Mod. Physics*, 1931, **3**, 280). According to Nielsen, " parallel " bands with a *Q*-branch structure are found at 2974, 2781, 1744, 1503, and 1166 cm.$^{-1}$, and " perpendicular " bands with more or less definite doublet structure at 2795, 1338, and 1040. The band at 1040 appears to need more careful examination. Other, feebler bands occur at longer wave-lengths. It is clear that not all the frequencies just given can be fundamentals, and it is not easy with such a well-spaced array of values to distinguish the fundamentals from the combination tones. A greater difficulty arises, however, with the group of frequencies at about 2800, since there is a distinct possibility of resonance splitting of one or more of these with a harmonic of a lower frequency such as 1503. It seems certain that ν_2 and ν_3, two of the symmetrical planar vibrations, are 1744 and 1503, and ν_5, one of the two antisymmetric planar frequencies, is 1338. The non-planar frequency ν_6 may be 1166. We can then assume $\nu_1 = 2781$, and $\nu_4 = 2795$, though it is perhaps better to take each as 2800. The remaining bands appear to be explicable by $2794 \cong 2\nu_3$, $1040 \cong (\nu_1 - \nu_2)$ or $(\nu_4 - \nu_2)$ according to its contour, when adequately known.

We shall only be concerned with the planar frequencies, and therefore take $\nu_1 = 2800$, $\nu_2 = 1744$, $\nu_3 = 1503$, $\nu_4 = 2800$, $\nu_5 = 1338$.

In the calculation of the force constants, we may first consider a simple valency force field, with a potential function involving four constants, k_1 (C=O), k_2 (C–H), with k_θ and k_ϕ as before. This fails to reproduce the values of the frequencies, the failure being parallel to that found with ethylene and allene, and relating mainly to the pair ν_2 and ν_3. It is natural, therefore, to explore the utility of a potential function of the form found to be so successful with ethylene and allene. This involves five constants and is as follows :

$$2V = k_1\Delta_{24}^2 + 2k_2\Delta_{12}^2 + k_\theta\Delta\theta^2 + 2k_\phi\Delta\phi^2 + k_3\Delta_{24}\Delta\theta$$

The equations for the symmetrical frequencies ν_1, ν_2, and ν_3 are then

$$\nu_1^2 + \nu_2^2 + \nu_3^2 = k_1[A] + k_2[B] + \frac{2k_\theta + k_\phi}{d_2^2}[C] - \frac{k_3}{d_2}[D] \quad . \quad . \quad (1)$$

$$\nu_1^2\nu_2^2 + \nu_1^2\nu_3^2 + \nu_2^2\nu_3^2 = k_1k_2[E] + \frac{k_1(2k_\theta + k_\phi)}{d_2^2}[F] + \frac{k_2(2k_\theta + k_\phi)}{d_2^2}[G] - \frac{k_2k_3}{d_2}\left[\frac{D}{m_1}\right] - \frac{k_3^2}{2d_2^2}[H] \quad . \quad . \quad (2)$$

$$\nu_1^2\nu_2^2\nu_3^2 = \frac{k_1k_2(2k_\theta + k_\phi)}{d_2^2}[H] - \frac{1}{2}\frac{k_2k_3^2}{d_2^2}[H] \quad . \quad . \quad . \quad . \quad . \quad (3)$$

and for the antisymmetric frequencies ν_4 and ν_5:

$$\nu_4^2 + \nu_5^2 = k_2[C] + \frac{k_\phi}{d_2^2}[B] + \frac{k_\phi}{d_1^2}[2A] + \frac{k_\phi}{d_1d_2}[J] \quad . \quad . \quad . \quad (4)$$

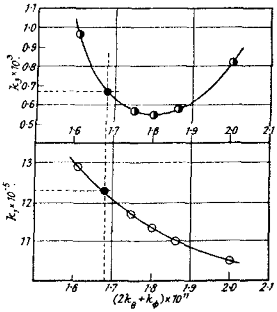
$$\nu_4^2\nu_5^2 = k_2k_\phi[G] + \frac{k_2k_\phi}{d_1^2}[2F] + \frac{k_2k_\phi}{d_1d_2}\left[\frac{J}{m_1}\right] \quad . \quad . \quad . \quad . \quad . \quad (5)$$

in which $A = 1/m_2 + 1/m_3$, $B = 1/m_1 + 2\cos^2\frac{1}{2}\theta/m_2$, $C = 1/m_1 + 2\sin^2\frac{1}{2}\theta/m_2$, $D = 2\sin\frac{1}{2}\theta/m_2$, $E = 1/m_1(1/m_2 + 1/m_3) + 2\cos^2\frac{1}{2}\theta/m_2m_3$, $F = 1/m_1(1/m_2 + 1/m_3) + 2\sin^2\frac{1}{2}\theta/m_2m_3$, $G = 1/m_1 + 2/m_1m_2$.

From equations (4) and (5) we can at once solve for k_2 and k_ϕ. We find $k_2 = 4{\cdot}1 \times 10^5$, and $k_\phi = 0{\cdot}93 \times 10^{-11}$. The value of k_2 is seen to be lower than that found for ethylene and allene. This difference may in part arise from the somewhat approximate value taken for ν_4, but there is no doubt that the value must be markedly less than the corresponding value for ethylene. The value for k_ϕ found for ethylene was $0{\cdot}594 \times 10^{-11}$. It is not surprising that in formaldehyde this constant is somewhat different, since, apart from other reasons discussed below, the angle involved in one case is $\widehat{HCC}$ and in the other $\widehat{HCO}$.

Turning to the three symmetric frequencies, we find that in order to reproduce the frequency $\nu_1 = 2800$ we must, regardless of plausible variations in the other constants, take $k_2 = 4{\cdot}3 \times 10^5$. This value is only slightly different from that obtained for k_2 from the antisymmetric vibrations. If the slight difference is real, it may be attributed to the necessity of a further interaction term in the potential function of the type $k_{23}\Delta_{12}\Delta$, in which case we should for the antisymmetric vibrations replace k_2 by $(k_2 - \frac{1}{2}k) = k_2'$ and for the symmetric by $(k_2 + \frac{1}{2}k) = k_2''$. This would give $k_2 = 4{\cdot}2 \times 10^5$ and $k = 0{\cdot}2 \times 10^5$. Assuming that $k_2'' = 4{\cdot}3 \times 10^5$ and $k_\phi = 0{\cdot}93 \times 10^{-11}$, we now have three unknown constants k_1, k_θ, and k_3, and only two frequencies so far unconsidered. Thus it is necessary to fix the value of one constant in order to calculate the other two. If we select a value for $(2k_\theta + k_\phi)$ it is possible from the equations (1), (2), and (3), by using the frequencies 2800, 1744, 1503, to calculate the associated values of k_1 and k_3. The results for different values of $(2k_\theta + k_\phi)$ are shown in Fig. 4. It is possible from the curves of this figure to read off the range of plausible values for the three constants. On the other hand, it is probably fair to estimate the force constant of the C–O link (k_1) from the value found with keten. If we take $k_1 = 12{\cdot}3 \times 10^5$, $(2k_\theta + k_\phi) = 1{\cdot}68 \times 10^{-11}$ and $k_3 = 0{\cdot}67 \times 10^{-3}$. Since k_ϕ was found above to be $0{\cdot}93 \times 10^{-11}$, this means that $k_\theta = 0{\cdot}375 \times 10^{-11}$.

FIG. 4.



Thus, taking the values $k_2 = 4{\cdot}2 \times 10^5$ $(k_2'' = 4{\cdot}3,\ k_2' = 4{\cdot}1)$, $k_1 = 12{\cdot}3 \times 10^5$, $k_\theta = 0{\cdot}375 \times 10^{-11}$, $k_\phi = 0{\cdot}93 \times 10^{-11}$, and $k_3 = 0{\cdot}67 \times 10^{-3}$, we find $\nu_1 = 2802$, $\nu_2 = 1744$, $\nu_3 = 1506$, $\nu_4 = 2806$, and $\nu_5 = 1340$. The errors are + 2, 0, + 3, + 6, + 2.

The relative amplitudes of the atomic nuclei in the different vibrations can now be evaluated as in the previous cases. The results are summarised in Table IV.

TABLE IV.

Type.	Frequency.	x_1.	y_1.	x_2.	y_2.	x_4.	y_4.
Symmetrical. $x_1 = x_2$; $y_1 = -y_2$	2802	+1·0	+1·46	−0·21	0	+0·03	0
	1744	+1·0	−2·47	−1·53	0	+1·02	0
	1506	+1·0	−0·58	+0·07	0	−0·18	0
Antisymmetric. $x_1 = -x_2$; $y_1 = y_2$	2806	+1·0	+1·68	0	−0·29	0	+0·01
	1340	+1·0	−0·15	0	+0·33	0	−0·23

These are used in Fig. 3. On calculating the energies as in the earlier examples, it is found that in the cases of the two vibrations *ca.* 2800, nearly all the energy is located in the C–H bonds. With the 1744 vibration, about 75% of the energy is in the C–O bond, and the greater part of the remainder is associated with angular deformation. With the 1506 vibration, this state of affairs is reversed, about 75% of the energy being in the deformation of the angle, and the bulk of the remainder in the vibration of the C–O bond. Examination shows a parallelism between these vibrations and those of ethylene, and the calculations of the energies show that care must be observed in attributing vibrations to particular parts of the molecule from the amplitude diagram alone.

5. *Carbon Dioxide.*—The linear vibrations of this molecule have been discussed in Part I. The observed frequencies require correction for resonance splitting and the potential function of simple valency force field needs modification. Using one cross term, so that

$$2V = k_1\Delta_{12}^2 + k_1\Delta_{23}^2 + k_2\Delta_{12}\Delta_{23}$$

it was found that $k_1 = 15{\cdot}24 \times 10^5$ and $k_2 = 2{\cdot}22 \times 10^5$. The significance of these results in connexion with the present calculations is discussed below.

6. *Carbon Suboxide.*—The four linear vibrations of this molecule have been treated in Part I, in which, by analogy with carbon dioxide, a potential function was used which incorporated cross terms representing the interaction between the C–O and C–C (k_3) bonds on the one hand, and between the C–C and C–C (k_4) bonds on the other. All the experimental data could be well interpreted by values $k_{CC} = 14{\cdot}87 \times 10^5$, $k_{CO} = 14{\cdot}15 \times 10^5$, $k_3 = 2{\cdot}3 \times 10^5$, and $k_4 = 2{\cdot}4 \times 10^5$. With $k_4 = 0$, values of k_3 less than $0{\cdot}85 \times 10^5$ give imaginary roots for the main constants k_{CC} and k_{CO}. With $k_4 = 0$ and $k_3 = 1{\cdot}0 \times 10^5$, the values obtained for k_{CC} and k_{CO} are obviously impossible. The significance of the chosen values of the constants k_3 and k_4 and of the resulting values of k_{CC} and k_{CO} are again discussed below.

7. *Carbon Monoxide and Acetylene.*—In Part II the force constant of the C–O bond in the ground state of carbon monoxide was shown to be $18{\cdot}6 \times 10^5$, and for acetylene $k_{CC} = 15{\cdot}8 \times 10^5$ and $k_{CH} = 5{\cdot}8 \times 10^5$.

Discussion.

The above results are collected together for comparison in Table V.

TABLE V.

Molecule.	k_{CH} $\times 10^{-5}$.	k_{CC} $\times 10^{-5}$.	k_{CO} $\times 10^{-5}$.	k_θ (HĈH) $\times 10^{11}$.	k_ϕ' (HĈC) $\times 10^{11}$.	k_ϕ'' (HĈO) $\times 10^{11}$.	$(2k_\theta + k_\phi')$ $\times 10^{11}$.	$(2k_\theta + k_\phi'')$ $\times 10^{11}$.	$k_\mu \times 10^3$.*	k_δ' (CĈC) $\times 10^{-5}$.	k_δ'' (CĈO) $\times 10^{-5}$
C_2H_4	5·02	9·8	—	0·342	0·594	—	1·279	—	0·637	—	—
CH_2:C:CH_2 ...	5·00	9·73	—	—	—	—	1·273	—	0·821	0·0	—
CH_2:CO	4·85	9·8	12·3	—	—	—	1·12	—	0·8	—	1·0
CH_2O	4·3	—	12·3	0·375	—	0·93	—	1·68	0·67	—	—
CO_2	—	—	15·24	—	—	—	—	—	—	—	2·2
C_3O_2	—	14·87	14·15	—	—	—	—	—	—	2·3	2·4
CO...............	—	—	18·6	—	—	—	—	—	—	—	—
C_2H_2	5·8	15·8	—	—	—	—	—	—	—	—	—

* k_μ is the constant expressing the cross term between the angle HĈH and the bond leading away from it, *e.g.*, in ethylene, the C=C bond.

The important conclusions to be inferred from these results are : (i) A comparatively simple potential-energy function has been found to interpret satisfactorily the vibration frequencies of each of the molecules of a closely related series. The constants and cross

terms involved in the potential function have a precise physical meaning, and can, subject to certain limitations, be carried over from one molecule to the next.

(ii) The numerical values of the corresponding constants required in the different cases are as a rule very close to each other, and differences can be understood and explained in terms of well-known phenomena. Moreover, this method of considering together related molecules of a series has the advantage that any ambiguities in the mathematical treatments are frequently removed.

(iii) The values of the force constants which have been derived appear to substantiate ideas arrived at previously by different methods, that two effects may be important in determining the electronic structures of the molecules considered. These effects are (*a*) *the existence of resonance hybrids, and* (*b*) *the occurrence of* electron drifts in a molecule as the result of the presence of some group which tends to attract or repel electrons. These several conclusions can be illustrated by a consideration of the data themselves.

First, the close parallelism between the relationships with ethylene and allene is very noticeable. The constants k_{CH}, k_{CO}, and $(2k_\theta + k_\phi)$ are within narrow limits identical, and the values of k_μ are close. Identical values of k_μ would not be expected. The parallelism between the results with keten and formaldehyde is less marked but still very noticeable.

In passing, however, from ethylene, allene, formaldehyde, and keten to carbon dioxide and suboxide, we notice an abrupt and marked alteration in the force constants of both C–C and C–O linkages. In the last two molecules the values are intermediate between the values associated with double and triple bonds. This result is interpreted as implying the presence of hybrid links, arising from the existence of a mesomeric structure. Such structures for these molecules are already well known. Attention should here be directed to one other point. In the case of allene, the cross-term constant k_{C-C-C} was found to be zero; with keten the corresponding constant k_{C-C-O} has a value which must be close to $1{\cdot}0 \times 10^5$. In the case of carbon dioxide there is no doubt that the same cross term is not $1{\cdot}0 \times 10^5$ but about $2{\cdot}2 \times 10^5$. In the same way with carbon suboxide k_{C-C-O} and k_{C-C-C} appear to have greater significance than might have been inferred from the consideration of allene and keten alone. We have assumed as very likely values in this case $2{\cdot}4 \times 10^5$ and $2{\cdot}3 \times 10^5$, although it must be admitted that these are approximations. It is certain, however, that the values are not far from the correct ones, since lower values for the two constants lead to values for the main constants which are either imaginary or obviously impossible. We may perhaps understand the relatively enhanced importance of such cross terms as k_{O-C-O} in carbon dioxide as follows. The molecule is supposed to exist as a hybrid of the forms (i) O=C=O, (ii) O–C≡O, and (iii) O≡C–O. If the C–O link 1, 2 contracts in a vibration, the molecule may be imagined as passing more towards the form (ii) or (iii), and consequently the C–O linkage 2, 3 will tend to lengthen. This means that the potential energy in the system will be greater than would be expected from the mere vibration of the one link, and would necessitate including an additional term in the potential function.

The variations in the C–H bond-constant in ethylene, allene, keten, and formaldehyde, and the associated variation in the bending constants are easily explained if it is supposed that the carbonyl group tends to draw electrons away from the remainder of the molecule. None of these molecules appears to be capable of existence in hybrid form. In formaldehyde the electronic drift will lead to greater weakening of the C–H bond than in keten. This is suggested by the figures calculated. In the same way in formaldehyde there is a small increase in k_θ which may suggest a greater localisation of electrons around the carbon atom. In keten the value of $(2k_\theta + k_\phi')$ is slightly lower than in ethylene and allene. We should expect the pull exerted by the carbonyl group to diminish on passing to the other end of the molecule. It would then be reasonable to expect only a small decrease in k_{CH}, as is found, but electrons in the C–C bond might to some extent leave the vicinity of the carbon atom of the methylene group, leading to the low value of $(2k_\theta + k_\phi')$.

The correlation of the calculated force constants with the interatomic distances, and the examination of the applicability of the relationships of Badger (*J. Chem. Physics*, 1934, **2**, 128; 1935, **3**, 710) and of Clark (*Phil. Mag.*, 1934, **18**, 459; 1936, **22**, 1137), are dealt with fully in a succeeding paper. It may, however, be observed that the value

assumed for the angle of the methylene group in formaldehyde leads to values for d_1 and d_2 (when calculated from the measured moments of inertia) both of which are in good agreement with the formulæ of Badger and Clark.

The above results and the conclusions inferred from them suggest that it may be profitable to consider related series of molecules in a similar manner to that described. It seems possible by such a systematic treatment to calculate force constants of linkages in simple molecules much more accurately than hitherto, and moreover, to do so without the necessity of employing potential-energy functions of undue complexity.

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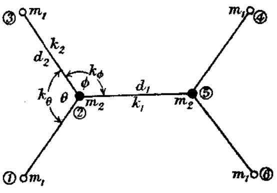
285. *Force Constants and Molecular Structure. Part IV. Ethylene and Tetrachloroethylene.*

By J. W. LINNETT and H. W. THOMPSON.

With a view to comparison with the corresponding data for ethylene, which have been previously determined, the force constants of the linkages in tetrachloroethylene are calculated from the normal vibration frequencies, a simple but apparently adequate potential function being used. The C–C link force constant in tetrachloroethylene appears to have a value between the normal values for a single and a double bond, and there are indications that the molecule is a resonance hybrid. The form of the vibrations is discussed.

IN Part II of this series (this vol., p. 1376) we have determined the force constants of the linkages in ethylene, and in Parts I and III (this vol., pp. 1291 and 1384) we have shown how variations of force constants can be related to problems of molecular structure. In the present paper the relationships with tetrachloroethylene are examined, and a comparison is made between the force constants of the C–C bond in ethylene and tetrachloroethylene. A preliminary note on these data has already been published (*Nature*, 1937, **139**, 509). The figures then given are here slightly amended as a result of small improvements in the mathematical treatment.



1. *Molecular Form and Assignment of Vibration Frequencies.*—Suppose the masses of carbon are m_2 and of chlorine m_1, and let the angles $\widehat{ClCCl}$ and $\widehat{ClCC}$ be θ and ϕ respectively. Let the C–C and C–Cl bond lengths be d_1 and d_2, and the force constants of these links for stretching k_1 and k_2. This nomenclature is the same as previously used for ethylene (see figure).

Electron-diffraction measurements have been made by Brockway, Beach, and Pauling (*J. Chem. Physics*, 1935, **57**, 2693), and by de Laszlo (*Nature*, 1935, **135**, 474). It is found that the shape of the molecule is determined by $\phi = 123° 45'$, *i.e.*, $\theta = 112° 30'$, $d_1 = 1{\cdot}38$ A., and $d_2 = 1{\cdot}73 \pm 0{\cdot}02$ A. The moments of inertia are too large for spectral determination, and the figures just given will therefore be taken.

Measurements of both the Raman spectrum and the infra-red spectrum have been described. The data on the Raman spectrum are summarised in Landolt–Börnstein (Ergänzungsband, pp. 992, 995), the values for the shifts being 1569(6), 509(2), 445(6), 345(3), 236(5). The infra-red spectrum was analysed by Ta-You Wu (*Physical Rev.*, 1934, **46**,

465), who found bands at 913 (strong), 802 (strong), 782 (strong), 755 (medium). As in the case of ethylene, the nine planar vibrations of the molecule fall into four symmetry groups. Class A contains the three totally symmetric oscillations ν_1, ν_2, ν_3; class B contains two vibrations (ν_4, ν_5) symmetric to the x–x plane and antisymmetric to the y–y plane. The three totally symmetric frequencies will be intense in the Raman effect. They can therefore be assigned to 1569 (ν_1), 445 (ν_2), and 236 (ν_3). The assignment of the other frequencies is less certain. The class B frequencies should be found as fundamentals in the infra-red, and it seems probable that $\nu_4 = 913$. This assignment of ν_1, ν_2, ν_3, ν_4 agrees with that suggested by Ta-You Wu and by Duchesne (*Nature*, 1937, **139**, 288). It is likely that the frequency ν_5 occurs in a region of the infra-red not yet explored, and the value taken for it is 345. Reasons for choosing this weak Raman frequency will be explained below. That the frequency $\nu_5 = 345$ should appear feebly in the Raman effect is perhaps understandable, since the measurements were made with liquid tetrachloroethylene.

2. *Calculation of the Force Constants.*—In the light of previous work by Urey and Bradley (*Physical Rev.*, 1931, **38**, 1969), Rosenthal (*ibid.*, 1934, **46**, 730), and others (see Sutherland, *Ann. Reports*, 1936, **33**, 59) on carbon tetrachloride and similar halogenated compounds, we should not expect the vibrations of tetrachloroethylene to comply at all closely with a potential function of the form of simple valency force field. The data confirm this supposition, and we have to explore the nature of the cross terms necessary to interpret the results satisfactorily. As with ethylene we must also, if possible, be able to account for the special importance of the particular cross terms used.

For any molecule of the ethylene type, it was shown in the previous paper that a potential function which involves no interaction between the two methylene groups, or between one methylene group and the C–C bond, leads to a relation between the frequencies ν_1, ν_2, ν_3, ν_4, ν_5 of the form

$$\nu_4^2 + \nu_5^2 + \frac{m_2 + 2m_1}{m_2} \cdot \frac{\nu_1^2\nu_2^2\nu_3^2}{\nu_4^2\nu_5^2} = \nu_1^2 + \nu_2^2 + \nu_3^2$$

This relationship was derived earlier by Mecke (*Z. physikal. Chem.*, 1932, **17**, *B*, 1), and by Sutherland and Dennison (*Proc. Roy. Soc.*, 1935, **148**, *A*, 250), whose method was more general. If we insert the values $\nu_1 = 1569$, $\nu_2 = 445$, $\nu_3 = 236$, $\nu_4 = 913$, and $\nu_5 = 345$, the left-hand side almost exactly balances the right. This is, in part, a justification for the assignment of ν_5 to 345. That such close agreement is found indicates that the potential function desired need not at any rate involve interaction terms between the opposite CCl_2 groups or between one of these and the C–C bond. In the case of ethylene the magnitudes of the frequencies suggested a possible interaction between ν_2 and ν_3. This clearly does not arise in the present case. On the other hand, the nature of the large chlorine atoms suggests the possibility of three types of interaction term, $k\Delta_{12}\Delta\theta$, $k\Delta_{12}\Delta_{23}$, and $k\Delta\phi_1\Delta\phi_2$. The first of these can be imagined as arising from the fact that when the link 1,2 is compressed, the approach of the two chlorine atoms may result in a widening of the $\widehat{ClCCl}$ angle. Alternatively, a decrease in θ might lengthen the C–Cl bonds. In the same way for the second cross term a decrease in the link length 1,2 might bring about an increase in the length 2,3. Again, expansion of ϕ_1 might result in a compression of ϕ_2 giving the third cross term. We shall therefore assume a potential function of the form

$$2V = k_1\Delta_{25}^2 + 4k_2\Delta_{12}^2 + 2k_\theta\Delta\theta^2 + 4k_\phi\Delta\phi^2 + 2k_3\Delta_{12}\Delta_{23} + 2k_\mu\Delta_{12}\Delta\theta + 2k_4\Delta\phi_1\Delta\phi_2.$$

For the totally symmetric oscillations this reduces to

$$2V = 4k_a\Delta_{12}^2 + k_b\Delta_{25}^2 + 4k_c\Delta\phi^2 + 2k_d\Delta_{12}\Delta\theta$$

in which $k_a = (k_2 + \frac{1}{2}k_3)$; $k_b = k_1$; $k_c = (2k_\theta + k_\phi) + \frac{1}{2}k_4$, and $k_d = k_\mu$.

Thus the number of independent constants is reduced to four. The equations for the three totally symmetric frequencies are then

$$\nu_1^2 + \nu_2^2 + \nu_3^2 = k_a\Big[P\Big] + k_b\Big[Q\Big] + \frac{k_c}{d_2^2}\Big[R\Big] + \frac{k_d}{d_2}\Big[S\Big]$$

$$\nu_1^2\nu_2^2 + \nu_2^2\nu_3^2 + \nu_1^2\nu_3^2 = k_a k_b\left[\frac{Q}{m_1}\right] + \frac{k_b k_c}{d_2^2}\left[\frac{Q}{m_1}\right] + \frac{k_a k_c}{d_2^2}\left[T\right] - \frac{k_d^2}{d_2^2}\left[\frac{T}{4}\right]$$

$$\nu_1^2\nu_2^2\nu_3^2 = \frac{k_a k_b k_c}{d_2^2}\left[\frac{Q}{m_1^2}\right] - \frac{k_b k_d^2}{d_2^2}\left[\frac{Q}{4m_1^2}\right]$$

in which $P = \left[\frac{1}{m_1} + \frac{2\cos^2\frac{1}{2}\theta}{m_2}\right]$, $Q = \left[\frac{2}{m_2}\right]$, $R = \left[\frac{1}{m_1} + \frac{2\sin^2\frac{1}{2}\theta}{m_2}\right]$,

$$S = \left[\frac{2\sin\frac{1}{2}\theta\cos\frac{1}{2}\theta}{m_2}\right], \quad T = \frac{1}{m_1}\left\{\frac{1}{m_1} + \frac{2}{m_2}\right\}$$

Using the same potential function, for the pair of class B frequencies, *i.e.*, symmetric to the *x–x* axis, we find

$$\nu_4^2 + \nu_5^2 = k_a P + \frac{k_c}{d_2^2}R + \frac{k_d}{d_2}S$$

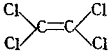
$$\nu_4^2\nu_5^2 = \frac{k_a k_c}{d_2^2}T - \frac{k_d^2}{d_2^2}\frac{T}{4}$$

With the values $k_a = 4{\cdot}9 \times 10^5$, $k_b = 6{\cdot}188 \times 10^5$, $k_c = 3{\cdot}891 \times 10^{-11}$, $k_d = -0{\cdot}33 \times 10^{-3}$, the frequencies calculated are $\nu_1 = 1571$, $\nu_2 = 443$, $\nu_3 = 231$, $\nu_4 = 915$, $\nu_5 = 347$, the errors being + 2, − 2, − 5, + 2, + 2. The approximate relative amplitudes of the nuclei in the different vibrations are given below.

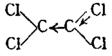
	ν.	x_1.	x_2.	y_1.
Totally symmetric.				
$x_1 = -x_6 = -x_4 = x_3$	1571	+1·0	−24·5	+0·90
$y_1 = y_6 = -y_3 = -y_4$	443	+1·0	+ 0·65	+1·95
$x_2 = -x_5$; $y_2 = y_5 = 0$	231	+1·0	+0·2	−0·47
Class [B]				
$x_1 = x_6 = x_3 = x_4$				
$y_1 = y_4 = -y_3 = -y_6$	915	+1·0	− 5·83	+0·86
$x_2 = x_5$; $y_2 = y_5 = 0$	347	+1·0	− 5·83	−8·3

DISCUSSION.

The potential function used above must be regarded as satisfactory, since with four independent constants it reproduces five frequencies very well. The main point of the calculation was to obtain a value for the force constant of the C–C bond in tetrachloroethylene, and to compare the value with that found for ethylene. The result shows that in tetrachloroethylene there is a marked fall in this constant (9·8 to 6·2 × 10^5). Using a different potential function, Duchesne has recently also arrived at this conclusion. It suggests that the molecule is a hybrid structure, formed from such possible types as



and



The value of the force constant of a carbon–carbon single bond is about 4·5 × 10^5. On the other hand, as pointed out by Badger (*J. Chem. Physics*, 1934, **2**, 128; 1935, **3**, 710), the mutual repulsion of the halogen atoms in a molecule of this type may result in a stretching of the linkages in the molecule.* This may to some extent be involved in the case of tetrachloroethylene, but we do not regard it as entirely responsible for the effect observed. It is interesting to notice that the decrease in the C–C bond constant in tetrachloroethylene goes parallel with an increase in the bond length. In ethylene r_e = 1·33 A. and in tetrachloroethylene, the electron-diffraction measurements give r_e = 1·38 A. Reference is made to this in the following paper. Assuming simple valency force field to apply to carbon tetrachloride, we find $k_{\text{CCl}} = 4{\cdot}38 \times 10^5$. That this value is not, however, satisfactory has been shown by Rosenthal (*Physical Rev.*, 1934, **46**, 730), since a complex potential function is really necessary. The value given by Sutherland (*loc. cit.*, p. 64) for k_{CCl} is

* Our attention was drawn to this point by Dr. G. B. B. M. Sutherland.

$3{\cdot}5 \times 10^5$. Thus it seems that in tetrachloroethylene the value for k_{CCl} is really greater than that of a normal single bond. Electron-diffraction measurements of the distance tend to confirm this conclusion.

It will be noticed that the constant for the bending of the $Cl\widehat{C}Cl$ angle in tetrachloroethylene is rather higher than the value usually found for such a constant. This may be connected with the large nature of the chlorine atoms. It should also be mentioned that the results found in the previous paper suggest that if tetrachloroethylene is really a resonance hybrid, we might then expect cross interaction terms of the form $k\Delta_{CCl}\Delta_{CC}$. Actually, adequate agreement is obtained without them.

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286. *Force Constants and Molecular Structure. Part V. The Relation between Force Constant and Bond Length.*

By H. W. THOMPSON and J. W. LINNETT.

The results of earlier calculations are collated with a view to examining the relationship between force constant and bond length for the linkages C–O, C–C, and C–H. In particular, the results are used to test the empirical relationships recently suggested by Badger and by Clark, which relate the force constant to the bond length. In the case of all three bond types, both sets of formulæ fit the data fairly well, but minor corrections are apparently necessary. The constants involved in each of the empirical equations are calculated. The results suggest the possibility of calculating bond lengths in some cases at least as accurately as they can be measured by the method of electron diffraction.

ATTEMPTS to obtain a relationship between the force constant of a linkage and its length have been made by several workers, notably by Badger (*J. Chem. Physics*, 1934, **2**, 128; 1935, **3**, 710), and by Clark (*Phil. Mag.*, 1935, **19**, 476; 1936, **22**, 1137). Badger found that the relationship $r_e = (C_{ij}/k_e)^{1/3} + d_{ij}$, whilst primarily designed for use with diatomic molecules (in all electronic states), could be applied with some success to the bonds in polyatomic molecules. In this relationship r_e is the bond length, and k_e the force constant; C_{ij} is a quantity which is almost constant, but varies slightly with different bonds according to the nature of the atom-pair forming the bond; d_{ij} is a quantity which varies more markedly for different bonds and depends on the position of the component atoms in the Periodic Table. Clark's formula, which was for use with frequencies, can be written so as to involve the force constant, in the form $k_e r_e^6 = 5{\cdot}863 \times 10^{-2} K^2 \mu/n$, in which μ is the reduced mass of the two nuclei forming the link, and n and K are quantities determined by the special type of link. Clark has attempted to make allowances for the specific factors involved in each particular link, *e.g.*, *ss* or *pp* binding, etc., these factors not being controlled in Badger's expression. Clark's relationship appears to be rather more satisfactory than Badger's for certain diatomic molecules, but has not so far been carried over to the case of polyatomic molecules.

In Part IV (preceding paper) and in Part VI (following paper) we have calculated the force constants of linkages in a series of polyatomic molecules. The resulting data make it possible to test the applicability of the above relations with respect to the bonds C–O, C–H, and C–C.

(i) *The Carbon–Oxygen Bond.*—Table I summarises the relevant data on this case, values of r_e being in A. The figures for carbon monoxide are due to Sponer ("Molekulspektren," Vol. I, pp. 32, 33). The force constants for the remaining molecules are those found in the

other papers of this series. The link lengths for keten and for carbon suboxide are given by Brockway (*Rev. Mod. Physics*, **1936**, 8, 261); those of carbon dioxide are the spectroscopic values; and that for formaldehyde is obtained from the measured moments of inertia by the considerations given in Part III.

TABLE I.

Molecule.	$k_e \times 10^{-6}$, dynes/cm.	$(1/k_e)^{1/3}$.	r_e, obs.	r_e, calc., Badger.	$(k_e)^{1/6} r_e$.	$(1/k_e)^{1/6}$.	r_e, calc., Clark.
CO $^1\Pi^+$	1·891	0·81	1·13	1·143	1·257	0·899	1·122
CO $^1\Sigma$	1·915	0·805	1·12	1·141	1·248	0·897	1·119
CO $^3\Sigma$	1·971	0·798	1·14	1·137	1·276	0·893	1·114
CO $^1\Pi$	0·923	1·026	1·232	1·266	1·216	1·0135	1·264
CO $^3\Pi$	1·217	0·939	1·205	1·216	1·245	0·968	1·207
CH_2O	1·23	0·933	(1·197)	1·213	1·239	0·966	1·204
$CH_2{\cdot}CO$	1·23	0·933	—	1·213	—	0·966	1·204
CO_2	1·524	0·868	1·16	1·176	1·245	0·932	1·162
C_3O_2	1·415	0·89	1·20 ± 0·02	1·188	1·271	0·944	1·177

For the C–O bond we should have, according to Badger, $r_e = 0{\cdot}571/k_e^{1/3} + 0{\cdot}680$ in which r_e is expressed in A. units and k_e is in the units 10^6 dynes/cm., *i.e.*, $C_{ij} = 0{\cdot}1861$ and $d_{ij} = 0{\cdot}680$. In Fig. 1 $(1/k_e)^{1/3}$ is plotted against r_e. It is seen that a fairly satisfactory

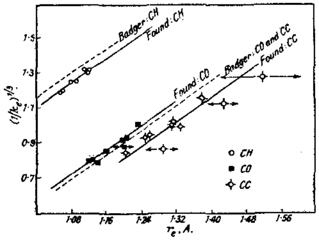

FIG. 1.

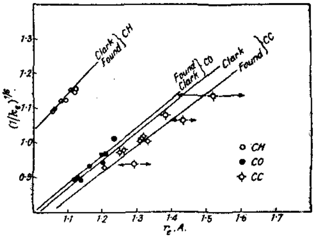

FIG. 2.

straight line can be drawn through the points, but this line does not coincide with that represented by Badger's equation; however, the slope of both lines is roughly the same. Assuming the slopes to be identical, we obtain for d_{ij} the value 0·667. This difference is well within the possible errors of Badger's empirical quantities.

According to Clark, for the C–O bond with *pp* binding, $n = 10$, $\mu = 48/7$, and $K = 9680$, so that $r_e k_e^{1/6} = 1{\cdot}247$ in the same units as above. To test this relationship, in Fig. 2 r_e is plotted against $(1/k_e)^{1/6}$. Clark's equation actually represents the most satisfactory line that could be drawn through the points, if it were to pass through the origin. The values of $k_e^{1/6} r_e$ given in Table I are seen to agree well with the equation, the mean value for all the points being 1·250.

If the force constants are assumed, and distances calculated, it is found that Clark's method gives remarkably good results, which are better than those obtained from the Badger relationship. Better results would of course be obtained with the latter if the value of d_{ij} found, *viz.*, 0·667, were taken.

(ii) *The Carbon–Hydrogen Bond.*—Table II summarises the data for the carbon–hydrogen bonds, r_e being given in A. The figures for the CH molecule are taken from Sponer (*op. cit.*, pp. 26, 27). The force constants for the other molecules are as found in the other papers of this series. The link length for methane is that given by Ginsburg and Barker (*J. Chem. Physics*, **1935**, 3, 668), that for hydrogen cyanide by Bartunek and Barker (*Physical Rev.*, **1935**, 48, 516), that for acetylene by Herzberg, Patat, and Spinks (*Z. Physik*, **1934**, 92, 87), and for the other molecules the lengths are given in the other papers of this series.

TABLE II.

Molecule.	$k_e \times 10^{-6}$, dynes/cm.	$(1/k_e)^{1/3}$.	r_e, obs.	r_e, calc., Badger.	$(k_e)^{1/6} r_e$.	$(1/k_e)^{1/6}$.	r_e, calc., Clark.
CH $^2\Pi$	0·442	1·313	1·12	1·084	0·977	1·146	1·108
CH $^2\Delta$	0·424	1·331	1·11	1·095	0·961	1·154	1·116
CH_4	0·498	1·261	1·093	1·055	0·974	1·123	1·086
C_2H_2	0·58	1·199	1·058	1·02	0·965	1·095	1·058
C_2H_4	0·502	1·258	1·08	1·053	0·962	1·122	1·085
CH_2O	0·43	1·325	(1·122)	1·091	0·971	1·151	1·113
HCN	0·57	1·206	1·06	1·059	0·965	1·098	1·062

According to Badger we should have $r_e = 0{\cdot}571/k_e^{1/3} + 0{\cdot}335$, *i.e.*, $C_{ij} = 0{\cdot}1861$ and $d_{ij} = 0{\cdot}335$. In Fig. 1 $1/k_e^{1/3}$ is plotted against r_e. It is seen that a fairly satisfactory straight line can be drawn through the points, but as in the case of the carbon–oxygen bond, the line is again not coincident with that represented by Badger's equation. As far as can be seen, the slopes are the same, and the facts can be interpreted satisfactorily by supposing that d_{ij} has the value 0·303. For the light atoms Badger's values of d_{ij} are somewhat unsatisfactory and the difference found is not at all unreasonable. For a bond M–H, M being an atom of the first short period of the Periodic Table, Clark gives 8050. It is clear that this value must vary slightly for the different atoms in the period, but he makes no allowance for this. If we plot (Fig. 2) $(1/k_e)^{1/6}$ against r_e, the points lie on a fairly good straight line. If we now take the mean of the calculated values of the product $k_e^{1/6} r_e$ (0·9665) and use the relationship $k_e^{1/6} r_e = 0{\cdot}9665$ to plot the line $1/k_e^{1/6}$ against r_e, it is seen that this line (which it must be remembered passes through the origin) is as nearly as could have been drawn coincident with the best line through the experimental points. The value of K deduced is 8680.

As in the case of the carbon–oxygen bond, calculation of the distances from the force constants is more satisfactory with Clark's relation than with Badger's, although again of course Badger's relationship would be more satisfactory with the modified value of d_{ij}. It should be noted, too, that the form of Clark's equation used here was determined for this special case.

(iii) *The Carbon–Carbon Bond.*—Table III summarises the relevant data for this case. The figures for the diatomic molecules are taken from Sponer. The force constants of the link in the remaining molecules are those found in the papers of this series. The link length in ethylene is that taken by Penney (*Proc. Roy. Soc.*, 1937, **158**, *A*, 306), in allene, cyanogen, carbon suboxide, and tetrachloroethylene from Brockway (*loc. cit.*), and in acetylene from the data of Herzberg, Patat, and Spinks (*loc. cit.*). The bond length in ethane is that quoted by Brockway, but it will be seen that the limits of error claimed are large.

TABLE III.

Molecule.	$k_e \times 10^{-6}$, dynes/cm.	$(1/k_e)^{1/3}$.	r_e, obs.	r_e, calc., Badger.	$(k_e)^{1/6} r_e$.	$(1/k_e)^{1/6}$.	r_e, calc., Clark.
C_2 $^3\Pi_u$	0·948	1·018	1·31	1·26	1·321	1·009	1·32
C_2 $^1\Pi_u$	0·910	1·032	1·315	1·27	1·335	1·016	1·328
C_2 $^3\Pi_g$	1·13	0·960	1·26	1·23	1·235	0·980	1·284
C_2 $^1\Pi_g$	1·181	0·946	1·25	1·22	1·217	0·9725	1·275
C_2H_4	0·98	1·007	1·33	1·255	1·334	1·003	1·31
C_2H_6	0·46 *	1·295	1·52 ± 0·1	1·42	?	1·138	1·49
CH_2:C:CH_2	0·973	1·010	1·31 ± 0·05	1·255	1·313	1·005	1·315
C_3O_2	1·487	0·876	1·29 ± 0·03	1·185	1·207	0·936	1·23
C_2H_2	1·58	0·858	1·205	1·18	1·116	0·9265	1·217
C_2Cl_4	0·62	1·173	1·38	1·35	1·492	1·083	1·417
C_2N_2	0·669	1·143	1·43 ± 0·03	1·335	1·529	1·069	1·40

* Mean value.

For this bond, we should have, taking Badger's figures, $r_e = 0{\cdot}571/k_e^{1/3} + 0{\cdot}680$, *i.e.*, $C_{ij} = 0{\cdot}1861$ and $d_{ij} = 0{\cdot}680$. In Fig. 1, it is seen that although a fairly satisfactory line can be drawn through the points, this line again does not coincide with that to be expected from Badger's equation. Again, it is seen that the slope of the lines is roughly the same, and assuming the slopes to be identical, we obtain for d_{ij} the value 0·735. The difference is well within the possible errors in Badger's quantities.

According to Clark, for the carbon–carbon bond with pp binding, $n = 8$, $\mu = 6$, and $K = 9680$. Then $r_e k_e^{1/6} = 1{\cdot}266$. The line obtained from this equation by plotting $(1/k_e)^{1/6}$ against r_e, does not pass satisfactorily through the points shown in Fig. 2. Taking the mean value of $k_e^{1/6} r_e$ from Table III to be 1·31, and assuming the equation $k_e^{1/6} r_e = 1{\cdot}31$, we see that in addition to passing through the origin this line passes satisfactorily through the points. This result would imply a value of K of 10,800.

As in the previous cases, the distances obtained from the force constants by using Clark's relation are more in accord with the observed values than are those obtained from Badger's equation.

Discussion.

It is seen in each of the above cases that the formulæ of Badger and of Clark can be carried over with fair success to a consideration of bonds in polyatomic molecules. If it were possible to obtain linkages of the atom-pairs with more widely differing force constants, as in the case of the diatomic molecules used by Badger, the agreement might appear very close. When applied to Badger's relationship, however, the results clearly indicate the specific nature of d_{ij}, and this quantity would appear to require more detailed specification than so far given by Badger, who makes no allowance for the peculiar nature of the atoms involved, apart from their horizontal row in the Periodic Table. In so far as the calculation of the distances from the force constants is concerned, Clark's method is strikingly successful. It seems indeed possible that this may in many cases provide a means of determining a bond length more accurately than is allowed by measurements of electron diffraction. This is especially the case with lighter atoms which are less suitable in diffraction work.

It is interesting to notice how this has been applied in the study of the vibrations of formaldehyde in the previous paper. In order to calculate the bond lengths from the measured moments of inertia, it is necessary to assume θ, the $H\widehat{C}H$ angle. The value assumed for θ gives bond lengths (for both C–H and C–O) which are related to the force constants in such a way as to agree closely with either of the above relationships. This is a separate justification for the assumption of the particular value of θ.

The figures for carbon suboxide are not entirely satisfactory, particularly as regards the C–C bond. This may arise from uncertain values of the bond lengths found by electron-diffraction measurements, although reference to a previous paper will show that minor errors in the values of the force constants may arise from lack of certain knowledge of the interaction terms of the potential function.

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Old Chemistry Department, Oxford. [*Received, June 25th, 1937.*]

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287. *Force Constants and Molecular Structure. Part VI. Compounds containing the Cyanide Link.*

By J. W. Linnett and H. W. Thompson.

The force constant of the C–N link in a series of molecules and ions is calculated from the known vibration frequencies, each case being examined separately. The results show that the molecule of cyanogen exhibits well-defined mesomerism, and this may also apply to the cyanogen halides. The thiocyanate ion may be regarded either as a resonance structure or as a structure involving links of 1½ or 2½ units respectively. The relationships between force constant and bond length are discussed.

In continuation of the previous papers of this series, we have calculated the force constants of the linkages in some linear polyatomic molecules each containing the carbon–nitrogen bond. Owing to the increased complications in the consideration of these molecules com-

pared with those previously studied, we have considered for the present only linear "parallel" vibrations, in order to exclude the force constants for the bending of angles and other related factors. Despite these simplifications, lack of experimental data and also in some cases the nature of the specific problems themselves frequently introduce ambiguities into the cases examined, but as shown below, it may be possible, as in the earlier cases, by a consideration of a related series of molecules to decide between two or more possible solutions in any given case.

(i) *The CN Diatomic Molecule.*—Regarding the molecule as m_1m_2 with a force constant k, we have $\nu^2 = k\{1/m_1 + 1/m_2\}$. Taking the data from Sponer ("Molekülspektren," pp. 38, 39) for three states, we obtain the results of Table I.

TABLE I

State.	ν.	$k \times 10^{-5}$, dynes/cm.	r, A.
$^2\Sigma^+$	2164	17·74	1·148
$^2\Pi$	1789	12·11	1·236
$^2\Sigma^+$	2069	16·21	1·169

(ii) *The Cyanide Ion.*—Taking the Raman frequencies for alkali cyanides (Kohlrausch, "Der Smekal-Raman Effekt," p. 321), we find $\nu = 2085$. This gives, as in (i), $k = 16{\cdot}38 \times 10^5$.

(iii) *Hydrogen Cyanide and Deuterium Cyanide.*—There are two parallel frequencies of each of these molecules $m_1m_2m_3$. Unfortunately, as shown by the calculations of Penney and Sutherland (*Proc. Roy. Soc.*, 1936, **156**, *A*, 654), it may be necessary to introduce an interaction term into the potential function. Writing

$$2V = k_1\Delta_{12}^2 + k_2\Delta_{23}^2 + k_3\Delta_{12}\Delta_{23}$$

we find

$$\nu_1^2 + \nu_2^2 = k_1\{1/m_1 + 1/m_2\} + k_2\{1/m_2 + 1/m_3\} - k_3\{1/m_2\}$$

$$\nu_1^2\nu_2^2 = k_1k_2\{(m_1 + m_2 + m_3)/m_1m_2m_3\} - \tfrac{1}{4}k_3^2\{(m_1 + m_2 + m_3)/m_1m_2m_3\}$$

Thus for hydrogen cyanide, there are three independent constants but only two frequencies. We can, however, take a third frequency from the isotopic molecule deuterium cyanide, and solve for the constants, assuming the cross-term constant to be the same in each case. Taking the data of Bartunek and Barker (*Physical Rev.*, 1935, **48**, 516) for hydrogen cyanide, we have $\nu_1 = 3313$, $\nu_2 = 2089$, and for deuterium cyanide $\nu_1 = 2630$. From these we find $k_{CN} = 18{\cdot}10 \times 10^5$, $k_{CH} = 5{\cdot}665 \times 10^5$, and $k_3 = -0{\cdot}65 \times 10^5$. For the bond lengths we have $r_{CN} = 1{\cdot}15$ and $r_{CH} = 1{\cdot}06$ A.

(iv) *Cyanogen.*—There are three linear vibrations of this molecule. Two are symmetrical, (ν_1, ν_2) and one is antisymmetrical (ν_3). The assignment and magnitudes are discussed by Sponer (*op. cit.*, p. 77) and by Mecke ("Hand- und Jahrbuch der Chem. Physik," Vol. 9, ii). We have $\nu_1 = 2335$, $\nu_2 = 860$, and $\nu_3 = 2150$.

If the masses 1, 2, 3, 4, are m_1, m_2, m_2, m_1, the force constants of the C–N and C–C bonds k_2 and k_1, and the cross-term constant k_3 (NCC),

$$2V = k_1\Delta_{23}^2 + k_2\Delta_{12}^2 + k_2\Delta_{34}^2 + k_3\Delta_{12}\Delta_{23} + k_3\Delta_{34}\Delta_{23}$$

and

$$\nu_1^2 + \nu_2^2 = k_2\{1/m_1 + 1/m_2\} + k_1\{2/m_2\} - k_3\{2/m_2\}$$

$$\nu_1^2\nu_2^2 = 2k_1k_2\{1/m_1m_2\} - k_3^2\{1/m_1m_2\}$$

$$\nu_3^2 = k_2\{1/m_1 + 1/m_2\}$$

We thus find $k_{CC} = 6{\cdot}69 \times 10^5$, $k_{CN} = 17{\cdot}51 \times 10^5$, and $k_{NCC} = 1{\cdot}17 \times 10^5$. The distances measured by electron diffraction are $r_{CC} = 1{\cdot}43 \pm 0{\cdot}03$ A. and r_{CN} $1{\cdot}16 \pm 0{\cdot}02$ A.

(v) *Cyanogen Halides.*—The vibration frequencies of the cyanogen halides have been considered by Penney and Sutherland (*loc. cit.*) and by West and Farnsworth (*J. Chem. Physics*, 1933, **1**, 402). Each of the molecules of the chloride, bromide, and iodide has two frequencies for linear vibration; for CNCl, $\nu_1 = 2201$, $\nu_2 = 729$; for CNBr, $\nu_1 = 2187$, $\nu_2 = 580$; for CNI, $\nu_1 = 2158$, $\nu_2 = 470$. The potential above of simple valency force

field being assumed for this type of molecule, *i.e.*, with no cross term, the force constants can be calculated as in case (iii) above, with $k_3 = 0$. We find

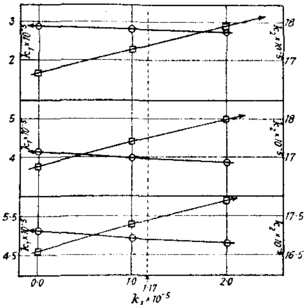
Molecule	NCCl	NCBr	NCI
$k_{CN} \times 10^{-5}$	16·65	16·81	16·75
$k_{CX} \times 10^{-5}$	5·15	4·17	2·94

These values have also been calculated by Penney and Sutherland and by West and Farnsworth, with results close to the values just given. It is clear, however, that we should make allowance for the relatively small interaction term in the potential function represented in (iii) by $k_3\Delta_{12}\Delta_{23}$. Unfortunately, we have no means of ascertaining with certainty the magnitude of k_3. We can proceed as follows. We assume successively values of $k_3 \times 10^{-5}$ of 0, + 1, + 2, and calculate k_1 and k_2. The results are summarised in Table II, and represented graphically in the figure.

TABLE II.

		Cyanogen chloride.	Cyanogen bromide.	Cyanogen iodide.
$k_3 = 0$	$k_1 \times 10^{-5}$	5·15	4·17	2·945
	k_2	16·65	16·81	16·75
$k_3 = 1 \times 10^5$	k_1	4·965	4·03	2·86
	k_2	17·33	17·45	17·33
$k_3 = 2 \times 10^5$	k_1	4·845	3·94	2·81
	k_2	17·92	18·04	17·91

In hydrogen cyanide the cross-term constant $k_3 = -0·65 \times 10^5$. In cyanogen it is $+ 1·17 \times 10^5$. *A priori* considerations would suggest that in the cyanogen halides the value of k_3 should be rather more like that in cyanogen. From the curves of the figure we notice that on putting $k_3 = 1·17 \times 10^5$ as in cyanogen, the values of k_1 and k_2 are: for CNCl 4·94 and 17·43; for CNBr 4·01 and 17·55; for CNI 2·85 and 17·43; *i.e.*, the values of k_{CN} are in each case very close to the value in cyanogen. For this reason, as well as for others, it seems probable that k_3 really has the value *ca.* $1·17 \times 10^5$.



(vi) *The Thiocyanate Ion.*—The frequencies of this ion were determined by Langseth, Nielsen, and Sørensen (*Z. physikal. Chem.*, 1934, **27**, *B*, 100), who give $\nu_1 = 750$, $\nu_2 = 2066$. Again we write a potential function involving k_{CS}, k_{CN}, and k_x, the cross-term constant. We then have three constants and only two frequencies. For different assumed values of k_x we find:

$k_x \times 10^{-5}$	−2	−1	0	+1	+2
k_{CS} ,,	5·86	5·60	5·33	5·09	4·93
k_{CN} ,,	12·89	13·61	14·36	15·08	15·73

It is certain that k_x lies between the limits + 2 and — 2, and probably it is positive. This means that k_{CS} must lie between the limits 5·9 and $4·9 \times 10^5$, and k_{CN} between 12·9 and $15·7 \times 10^5$. In carbon disulphide and carbonyl sulphide, according to Penney and Sutherland (*loc. cit.*), $k_{CS} = 7·6$ and $8·0 \times 10^5$, corresponding to the C–S double link. According to Sidgwick ("The Covalent Link," p. 123) the value of k_{CS} in methylthiol is $3·01 \times 10^5$ (single C–S link). Thus the value of k_{CS} in the thiocyanate ion for any plausible value of the cross term k_x will be intermediate between those for a single and a double bond. In the same way the value of k_{CN} is higher than would be expected for a double bond and lower than would apply to a triple bond. This is discussed further below.

(vii) *Mercuric Cyanide and the Argentocyanide Ion,* $Ag(CN)_2^-$.—Taking these structures to be $m_1m_2m_3m_2m_1$ and numbering the atoms 1, 2, 3, 4, 5, we can write in general

$$2V = k_2\Delta_{12}^2 + k_2\Delta_{45}^2 + k_1\Delta_{23}^2 + k_1\Delta_{34}^2 + k_3\Delta_{12}\Delta_{23} + k_3\Delta_{34}\Delta_{45} + k_4\Delta_{23}\Delta_{34}$$

The two symmetric frequencies are then given by

$$\nu_1^2 + \nu_2^2 = k_2\{1/m_1 + 1/m_2\} + (k_1 + \tfrac{1}{2}k_4)\{1/m_2\} - k_3\{1/m_2\}$$

$$\nu_1^2\nu_2^2 = k_2\{k_1 + \tfrac{1}{2}k_4\}\{1/m_1m_2\} - \tfrac{1}{4}k_3^2\{1/m_1m_2\}.$$

Since only the two symmetrical frequencies are known, we need only consider this pair. Again, there are here three independent constants *with only two frequencies. For mercuric* cyanide $\nu_1 = 260$, $\nu_2 = 2197$, and for the argentocyanide ion $\nu_1 = 239$ and $\nu_2 = 2130$ (Kohlrausch, "Der Smekal–Raman Effekt," p. 321). By assuming values of k_3 over a *plausible range* (-2 *to* $+2 \times 10^5$) the following values of the other constants are obtained :

$k_3 \times 10^{-5}$		−2.	−1.	0.	+1.	+2.
$Hg(CN)_2$	k_{HgC}	1·06	1·07	1·05	1·03	1·04
	k_{CN}	16·89	17·43	17·98	18·52	19·05
$[Ag(CN)_2]^-$	k_{AgC}	0·88	0·90	0·88	0·87	0·89
	k_{CN}	15·85	16·38	16·93	17·47	18·00

It is not possible to select a satisfactory value for k_3 on *a priori* grounds. If we choose $k_{CN} = 18·1$, as in hydrogen cyanide, we should find for mercuric cyanide $k_{HgC} \cong 1·2$ and $k_3 \cong + 0·2 \times 10^5$, and for the argentocyanide ion $k_{AgC} \cong 0·89$ and $k_3 \cong + 2·2 \times 10^5$. The value of the cross-term constant in the latter ion seems very large. If we take k_{CN} as in cyanogen and in the cyanogen halides (17·5) we should obtain for mercuric cyanide $k_3 \cong - 0·9$ and for the argentocyanide ion $k_3 \sim + 1·05 \times 10^5$. The contrast between the last *two cases may arise in some way either from the anomalous nature of the mercury atom,* previously noticed, or from the ionic nature of the argentocyanide ion.

Discussion.

There seems little doubt that the "normal" value of the force constant of the C–N triple bond is *ca.* $18·1 \times 10^5$. In cyanogen the value of k_{CN} is 17·51, *i.e.*, low. It is also *seen that in cyanogen the value of the carbon–carbon force constant lies well intermediate* between the values of a single carbon–carbon bond (*ca.* 4·5) and a double carbon–carbon bond (9·8) (previous paper). These facts suggest that cyanogen is a mesomeric structure, a fact which has already been suggested by measurements of the bond length.

The relationships are similar in the case of the cyanogen halides. The value of k_{CN} in *each case is ca.* $17·5 \times 10^5$, *and in the case of cyanogen chloride* k_{CCl} ($4·94 \times 10^5$) *is notice*ably higher than in the halogenated methanes, where its value is "normal." The structure of the cyanogen halides might then be written N $\leftrightarrows$ C $\leftrightarrows$ X. It should be pointed out that in calculating the value of $k_{CHal.}$ in these compounds, values higher than the "normal" would be obtained for any plausible value of the cross-term constant.

The thiocyanate ion is also found to have values for the force constants which correspond to non-integral bonds. We could write two possible mesomeric structures : $[\bar{S} - C \equiv N]$ and $[S = C = \bar{N}]$.

Actually the structure of the ion may be a hybrid of these possibilities. On the other *hand, in this molecule the facts could be explained equally well by the assumption of one* single electronic structure [$\cdot\ddot{S}\!:\!C\!\vdots\!\dot{N}\cdot$], which implies the existence of bonds of $1\frac{1}{2}$ and $2\frac{1}{2}$ units.

Another point to which attention should be drawn is the result that in hydrogen cyanide *the value of* k_{CH} ($5·66 \times 10^5$) *is higher than that usually* associated with a single *C–H* bond ($5·0 \times 10^5$ in ethylene and methane). The result is parallel to that found with acetylene and deuteroacetylene, where the C–H bond force constant is *ca.* $5·8 \times 10^5$. This variation in C–H force constants has been discussed in the previous paper.

In calculating the cross-term constant in the above molecules and in previous cases, *data have been accumulated which reveal a possibly general rule regarding the magnitudes* of these constants. With molecules showing the phenomenon of a hybrid structure, the value of the interaction constant seems to be positive and relatively large, whereas in the

case of simpler structures the values are small and may be positive or negative. A possible interpretation of this for the special case of carbon dioxide was referred to in Part III. In the present cases the peculiarity is again noticed.

It is possible to test the empirical equations of Badger (*J. Chem. Physics*, 1934, **2**, 128; 1935, **3**, 710) and of Clark (*Phil. Mag.*, 1934, **18**, 459; 1936, **22**, 1137) relating the force constant of the C–N link with its length. The data are summarised below, values of r being in A.

Molecule.	$k \times 10^{-6}$, dynes/cm.	r, obs.	$(1/k)^{1/3}$.	r, calc., Badger.	$(1/k)^{1/6}$.	$k^{1/6} . r$.	r, calc., Clark.
CN $^2\Sigma^+$	1·774	1·148	0·826	1·152	0·909	1·263	1·142
CN $^2\Pi$	1·211	1·236	0·938	1·216	0·969	1·276	1·218
CN $^2\Sigma^+$	1·621	1·169	0·851	1·166	0·923	1·267	1·160
HCN	1·810	1·15	0·821	1·149	0·906	1·270	1·138
C_2N_2	1·751	1·16 ± 0·02	0·830	1·154	0·911	1·273	1·145

Badger's equation would be written in the form $r_e = 0{\cdot}571/k_e^{1/3} + 0{\cdot}680$. This represents a straight line plot of $(1/k)^{1/3}$ against r_e. The data given are in fairly good agreement with this line, and the distances determined from the force constants are frequently close to the values found experimentally.

Clark's equation would be $k_e^{1/6}r_e = 1{\cdot}257$. This represents a straight line through the origin if $(1/k)^{1/6}$ is plotted against r_e, but the line does not pass through the points observed at all. On the other hand, if we write $k_e^{1/6}r_e = 1{\cdot}270$ (the mean observed value), a very adequate agreement is obtained. If, as in the previous paper, $k_e r_e^6 = 5{\cdot}863 \times 10^{-2} \times K^2\mu/n$, we have, since $n = 9$ and $\mu = 84/13$, $K = 9982$.

We thank the Government Grant Committee of the Royal Society and Imperial Chemical Industries for financial assistance, and one of us is grateful to the Department of Scientific and Industrial Research for a Maintenance Allowance.

Old Chemistry Department, Oxford. [*Received, June 25th*, 1937.]

288. *The Influence of Solvents and of Other Factors on the Rotation of Optically Active Compounds. Part XXXV.* Attractive Power and Solvent Effect on Rotation.*

By T. S. Patterson and Gladys M. Holmes.

Although the rotation of optically active compounds often varies very greatly with the nature of inactive liquids used as solvents, no satisfactory suggestion has hitherto been made to correlate any property or properties of the solvent with the alteration thus produced. The following experiments had their origin in the idea that if an active compound, such as ethyl tartrate, were distributed between two, so-called immiscible, solvents, the relative attractive power, as it may be termed, of these two solvents for the ethyl tartrate might show some proportionality to the corresponding changes in rotation.

It is difficult, however, to find pairs of immiscible organic liquids, and it is therefore essential to attack the problem by using water as an intermediary. Moreover, it is not easy to find active substances which combine the properties of (1) being soluble in water, (2) being also soluble in organic solvents, and (3) showing considerable changes of rotation in different solvents; so that the field of experiment is somewhat limited.

Our method of procedure—to take a definite example—was to shake thoroughly together 50 c.c. of water, 50 c.c. of nitrobenzene, and 10 c.c. (12 g.) of ethyl tartrate, in a separating funnel, at room temperature, without any special precaution to maintain a definite temperature, since it was desired in the first place to obtain a general view in this particular field. After an hour the layers were run off, and the density of each determined by means of the Westphal balance, greater accuracy not being necessary in the circum-

* Part XXXIV, this vol., p. 581.

stances; and the rotation of each layer was observed, in a 400-mm. tube, for sodium light, since many of the data upon which we had to rely are given in the literature only for sodium light. It was then possible, from results already published, to calculate the amount of ethyl tartrate in each layer. This quantity may be expressed either as percentage composition p or as concentration c (g. of active substance per 100 g. or 100 c.c. respectively of solution); and it is difficult to say which of these it is better to use.

In the example mentioned above, the rotation actually observed in the nitrobenzene layer was $+11°$, the density was 1·157, whence $p = 7·2$, $c = 8·32$, and $[\alpha]_D = +33°$. Similarly the data for the aqueous layer were α_D (400 mm.) $= +13·36°$, the density 1·039, $p = 13·2$, $c = 13·68$, and $[\alpha]_D = 24·4°$. Of the 12 g. of ethyl tartrate added, 4·16 g. (half the value of c) had gone apparently into the nitrobenzene layer, and 6·84 g. into the aqueous layer, totalling 11·00 g., a discrepancy of 1 g.

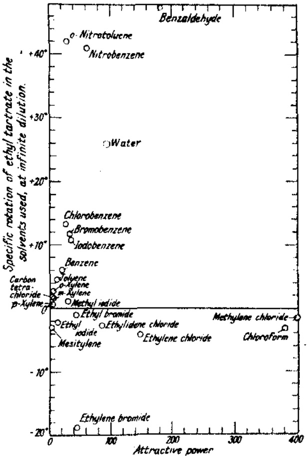
A.	*B.*	*C.*	*D.*	*E.*	*F.*	*G.*	*H.*	*K.*
	Concn. (c) of ethyl tartrate in		Attractive power of solvent (H_2O = 100).	$[\alpha]^{20°}$ at $c = \infty$.	α, obs. (l = 4), in		d, obs., in	
	Solvent.	H_2O.			Solvent.	H_2O.	Solvent.	H_2O.
Water	—	—	100·0	26·2° [2]	—	—	—	—
Benzene	3·52	16·84	20·9	6·1 [2]	0·98°	15·83°	0·880	1·04
Toluene	2·26	18·94	11·9	4·6 [2]	0·47	17·95	0·870	1·041
o-Xylene	1·06	19·76	5·36	2·7 [2]	0·15	19·00	0·883	1·043
m-Xylene	1·14	19·76	5·8	1·8 [2]	0·06	19·22	0·871	1·043
p-Xylene	0·95	19·76	4·8	0·7 [2]	0·01	19·15	0·867	1·043
Mesitylene	0·87	20·26	3·85	− 3·0 [2]	− 0·13	19·45	0·869	1·045
Chlorobenzene	4·44	16·66	26·65	13·3 [3]	2·31	15·60	1·113	1·035
Bromobenzene	6·10	17·64	34·6	11·7 [3]	3·50	16·72	1·49	1·038
Iodobenzene	6·24	17·44	35·8	11 [3]	3·37	17·59	1·623	1·171
Nitrobenzene	8·32	13·68	60·8	41 [4]	11	13·36	1·155	1·036
o-Nitrotoluene	4·74	16·74	28·3	42 [4]	7·98	15·79	1·160	1·033
Benzaldehyde	12·48	6·86	182·0	47·5 [5]	20·80	7·76	1·040	1·009
Carbon tetra-chloride	0·78	20·28	3·85	1·9 [6]	0·09	19·02	1·592	1·040
	1·11 *	22·38 *	4·96 *	—	—	—	—	—
	1·34 †	22·66 †	5·91 †	—	—	—	—	—
Chloroform	20·88	5·54	377·0	− 3·2 [1]	2·85	5·18	1·454	1·009
	18·82 *	4·88 *	386 *	—	—	—	—	—
	18·00 †	6·00 †	300 †	—	—	—	—	—
Methylene chloride	19·83	4·90	405·0	− 1·60 [6]	− 2·61	5·25	1·304	1·011
	18·97 †	5·03 †	377·5 †	—	—	—	—	—
Ethyl bromide	6·50	15·68	41·5	− 0·95 [6]	− 0·66	14·74	1·415	1·032
	—	—	43·8 ‡	—	—	—	—	—
	—	—	43·7 ‡	—	—	—	—	—
Ethylene bromide	6·92	15·64	44·2	−18·8 [6]	− 4·52	14·88	1·98	1·03
Ethylene chloride	14·03 ‡	9·97 ‡	140·7 ‡	− 4·2 [6]	− 2·06	+ 8·55	—	—
	14·36 ‡	9·64 ‡	148·8 ‡	—	− 2·10	+ 8·60	—	—
Ethylidene chloride	11·00 ‡	13 ‡	84·6 ‡	− 1·7 [6]	− 1·38	+11·03	—	—
	11·17 ‡	12·83 ‡	87 ‡	—	− 1·44	11·32	—	—
Methyl *iodide*	5·67 ‡	18·33 ‡	30·8 ‡	+ 1·08 [6]	+ 0·16	+15·2	—	—
	5·84 ‡	18·18 ‡	32·1 ‡	—	+ 0·16	+14·98	—	—
Ethyl iodide	2·62 ‡	21·38 ‡	12·3 ‡	− 2·2 [6]	− 0·17	+17·23	—	—
	2·79 ‡	21·21 ‡	13·2 ‡	—	− 0·24	+17·20	—	—

[1] J., 1905, **87**, 320. [2] J., 1902, **81**, 1107. [3] J., 1908, **93**, 945. [4] J., 1908, **93**, 1856. [5] J., 1909, **95**, 322. [6] J., 1908, **93**, 370—371.

It appears, therefore, that what may be called the attractive power (perhaps not necessarily the same as solubility) for ethyl tartrate of nitrobenzene is less than that of water approximately in the ratio 4·16 to 6·84; or, the attractive power of water being represented (for convenience) as 100, that of nitrobenzene is 61. When most of the data recorded in the table had been obtained, several of them were redetermined by a slightly different, and probably more accurate, process. In the case of water and chloroform, for example, 50 c.c. of water previously shaken with chloroform, 50 c.c. of chloroform previously shaken with water, and 10 c.c. of ethyl tartrate, were mixed and then examined as before, the temperature being noted. The density of each layer was determined by a pyknometer, and the rotation observed for sodium light, and mercury green light, a 400-mm. tube being used. From these data the approximate value of p for each layer was found. Several solutions

were then made up of ethyl tartrate in the moist chloroform, and several in water saturated with chloroform, and examined polarimetrically. From concentration curves from these data, values of p were obtained. In the accompanying table, the results obtained by this method are marked with an asterisk.

The results for carbon tetrachloride, chloroform, and ethylene chloride were further checked as follows. To 50 c.c. of chloroform and 50 c.c. of water, 10 c.c. of ethyl tartrate were added and shaken as in the original experiments. The chloroform layer was run off in instalments, into a small distilling flask, and the chloroform distilled away. The last traces of solvent were then expelled by passing air, dried by bubbling slowly through concentrated sulphuric acid in a spiral, into the flask close to the surface of the liquid, the flask and contents being heated on the water-bath and weighed at intervals until of constant weight. In these cases the rotation was not examined. These experiments were carried out by Mr. A. J. Summers and are marked †. In some other experiments, carried out by Mr. J. Devine, the above procedure was followed, but since the solvent had not been included in the first set of experiments, the rotations of the solutions—but not the densities—were also determined. These experiments are marked ‡. This procedure could clearly be applied only to fairly volatile solvents.



The data obtained are given in the accompanying table. Cols. B and C show the weight of ethyl tartrate passing into the solvent and the aqueous layers respectively; the observed rotations are shown in cols. F and G; cols. H and K give the densities of the solvent and the aqueous layers; from these data, p and $[\alpha]_D$ of the various solutions examined can be calculated if desired. Col. E shows the rotation in the various solvents at *infinite dilution*. The methods adopted, from the nature of the case, cannot lay claim to any great accuracy. The experimental error is necessarily fairly large, and it is not easy to see how it could be greatly reduced. The results, however, are sufficient to give some general conspectus of the field, and since the differences in behaviour are, on the whole, striking, the experimental error has no undue influence. It should be noticed that in cols. B and C, the experimental error, which is already considerable, is doubled, since the data were obtained actually for 50 c.c. but are here given for 100 c.c. The numbers in these two columns ought to add up to 24; in the experiments marked † and ‡ they do add up to 24 since one of them is obtained by difference.

It is difficult to decide how comparison ought to be made amongst these data. It is quite obvious that much might depend on whether concentration were expressed as c or p. A solution of $p = 20$ in ethylene bromide is very different in constitution from one of $c = 20$, on account of the high specific gravity of the solvent.

It is also difficult to say how changes in rotation ought to be expressed. We do not know what is to be regarded as the rotation of an ethyl tartrate molecule free from external forces. In the homogeneous condition any molecule may be looked upon as under the solvent influence of that particular liquid. We cannot tell whether a given solvent raises or depresses the rotation of a *free* molecule of the active substance, we only know that in other solvents it has a greater or a less value than when dissolved in molecules identical with itself.

It seems, therefore, best, simply to compare the actual rotation in a given solvent with

the attractive power of that solvent, and to express concentration as *c*, since this is easiest to visualise.

Our main results, namely, those of cols. D and E, are the most important, since they give a direct comparison of the attractive power of the solvent with the specific rotation which it produces in ethyl tartrate, at infinite dilution. They are represented also in the diagram, which makes them clearer than can any verbal description. The specific rotation at infinite dilution in a given solvent is plotted vertically, and the attractive power of the solvent, as compared with that of water set equal to 100, is plotted horizontally.

There is obviously no general relationship; but, to some extent, analogous solvents are grouped together.

The aromatic hydrocarbons have astonishingly little attractive power, but such as they have increases from mesitylene in a regular manner through *p*-xylene, *m*-xylene (which is slightly out of sequence), *o*-xylene, and toluene to benzene, whilst the rotation increases in a corresponding fashion. The introduction of methyl groups into the benzene molecule diminishes the attractive power of the solvent.

Chlorobenzene, bromobenzene, and iodobenzene show a behaviour opposite to that of the hydrocarbons; whilst the attractive power is least in chlorobenzene and greatest in iodobenzene, the rotations are in the opposite sequence. *o*-Nitrotoluene and nitrobenzene show a somewhat similar behaviour, the rotation being less as the attractive power increases, but, although the attractive power is not much different from that of chlorobenzene, the rotation is almost three times as great. Benzaldehyde, with a much greater attractive power, produces a higher, not a lower, rotation.

Perhaps our most interesting results concern the chloromethane derivatives. The attractive power of carbon tetrachloride is very slight, only 4; but the change to chloroform brings about an enormous change in attractive power, since that of chloroform is 375. On shaking an aqueous solution of ethyl tartrate with carbon tetrachloride, very little of the ester is extracted: about 20 times as much remains in the aqueous solution as passes into the carbon tetrachloride. Chloroform, on the other hand, extracts almost four times as much ester as remains in the water. There is, however, little change in rotation to correspond to this. The rotation in carbon tetrachloride has a small positive value, and in chloroform it has a small negative value. Methylene chloride has a somewhat greater attractive power than chloroform, but confers a rather higher rotation value.

It is interesting to notice that the nearer the solvent approaches to methane, the greater does the attractive power become, which is exactly the opposite to what seemed to be observed in the aromatic hydrocarbons, where the introduction of methyl groups very considerably diminishes the attractive power. Ethyl chloride and ethylene bromide have almost the same attractive power, but the rotation is considerably lower in the latter case than in the former. Ethylidene chloride has a fairly high attractive power, little less than that of water, whereas ethylene chloride has an attractive power considerably greater than that of water. Methyl iodide has an attractive power about 2½ times as great as that of ethyl iodide, but the attractive powers of these last four solvents are not in the same order as the specific rotations at infinite dilution.

The foregoing experiments, whilst failing to discover any definite connection between the attractive power (as here defined) of various organic solvents for ethyl tartrate, and the rotation produced in ethyl tartrate, at infinite dilution, by these solvents, do reveal some interesting facts regarding the attractive power of the solvents used.

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289. *Ethoxides and* iso*Propoxides of Manganese and Rhenium.*

By J. Gerald F. Druce.

Manganese and rhenium ethoxides and *iso*propoxides, $Mn(OR)_2$ and $Re(OR)_3$, have been prepared by the interaction of the chlorides of the elements with sodium ethoxide and *iso*propoxide. The products are only stable in dry air, since water very readily hydrolyses them.

Compounds of the halides of manganese and rhenium with one molecule of ethyl or *iso*propyl alcohol have also been obtained.

Neither manganese nor rhenium dissolves in or reacts with methyl, ethyl, or *iso*propyl alcohol to give an alkoxide, but the ethoxides and iso*propoxides* of both metals have been obtained by the interaction of dry alcoholic solutions of their halides with the appropriate sodium alkoxide, *e.g.*, $ReCl_3 + 3NaOEt = 3NaCl + Re(OEt)_3$. Manganese ethoxide, $Mn(OC_2H_5)_2$, has already been made (Kandelaky, Setaschwili, and Tawberidge, *Kolloid-Z.*, 1935, **73**, 47), but the other compounds have not previously been described.

Reactions with sodium methoxide were inconclusive.

In the course of the work the following *alcoholates* of manganese and rhenium halides with alcohols were obtained: $MnCl_2,C_2H_5OH$; $MnCl_2,C_3H_7OH$; $MnBr_2,C_2H_5OH$; $MnBr_2,C_3H_7OH$; $ReCl_3,C_2H_5OH$; $ReCl_3,C_3H_7OH$. All these decomposed when strongly heated, usually giving off the alcohol accompanied by some alkyl halide and hydrogen halide, and the residue contained halogen.

No compounds were obtained with ether, but since compounds of tervalent rhenium were prepared, it was thought of interest to try to make the compound, $MnBr_3,3(C_2H_5)_2O$, described by Ducelliez and Raynaud (*Compt. rend.*, 1914, **158**, 576), with a view to converting it into a manganese trialkoxide. It was found, however, that when bromine is added to manganese under ether, reaction occurs and a lower layer of liquid separates, as Ducelliez and Raynaud state, but no compound of manganese tribromide was extracted. Manganese bromide was identified, together with certain organic bromine-containing compounds (*e.g.*, monobromoacetaldehyde).

Experimental.

Commercial absolute ethyl and *iso*propyl alcohols were dried over and then distilled from calcium shavings. When powdered manganese or rhenium was placed in either ethyl or *iso*propyl alcohol and heated under reflux for some hours, there was no reaction, and the filtrates left no residue on evaporation.

The alcohol compounds of the manganese halides were obtained by adding excess of manganese carbonate to a dry alcoholic solution of the hydrogen halide. The filtered solutions were placed in vacuum desiccators over calcium chloride, yielding crops of pink crystals of the salts with alcohol of crystallisation. These crystals, when separated, dried, and left in the vacuum desiccator for some days, underwent no further change.

The *compound*, $MnCl_2,C_2H_5OH$, obtained as bright pink crystals (Found: C, 13·75; H, 3·8; Cl, 41·1. $C_2H_6OCl_2Mn$ requires C, 14·0; H, 3·6; Cl, 41·3%), was stable in air and soluble in water and alcohol but not in ether. On heating, decomposition began below 100°, and at somewhat higher temperatures ethyl chloride was evolved, together with hydrogen chloride. The *compound*, $MnCl_2,C_3H_7OH$ (Found: C, 19·0; H, 5·5; Cl, 38·0. $C_3H_8OCl_2Mn$ requires C, 19·3; H, 5·3; Cl, 38·2%), was similar in appearance and properties. It began to lose alcohol at 113° in absence of air, and it fused below red heat, giving off some *iso*propyl chloride although the residue still contained much chloride.

The *alcoholate*, $MnBr_2,C_2H_5OH$ (Found: Br, 60·5. $C_2H_6OBr_2Mn$ requires Br, 61·3%), was obtained as pink crystals, which, when dry, showed no loss in weight when left in the desiccator for 14 days. By warming in a current of nitrogen, the alcohol was slowly lost, and anhydrous manganese bromide remained. When the compound was heated rapidly and more strongly, ethyl bromide and hydrogen bromide accompanied the alcohol driven off. The pink *compound*, $MnBr_2,C_3H_7OH$ (Found: C, 12·8; H, 2·9; Br, 57·7. $C_3H_8OBr_2Mn$ requires C, 13·1; H, 2·7; Br, 58·2%), behaved like the corresponding chloride.

The *compound* $ReCl_3,C_2H_5OH$ was obtained from an alcoholic solution of rhenium trichloride as brown-green crystals (Found : C, 6·65; H, 2·4; Re, 54·3 *; Cl, 31·0. $C_2H_6OCl_3Re$ requires C, 7·1; H, 1·8; Re, 55·0; Cl, 31·4%). It decomposed on heating without fusing, ultimately leaving no residue. It was soluble in water, alcohol, and ether. The aqueous solution at first gave no precipitate with silver nitrate, but addition of dilute nitric acid caused silver chloride to separate. With alkalis, and with water on boiling, rhenium sesquioxide separated, but was rapidly oxidised in air to the dioxide. The dried sesquioxide was more stable, and some of this oxide was soluble in hydrochloric acid even after several days' keeping.

$ReCl_3,C_3H_7OH$, similarly prepared from *iso*propyl alcohol (Found : Re, 51·8; Cl, 30·3. $C_3H_8OCl_3Re$ requires Re, 52·8; Cl, 30·2%), resembled the foregoing compound very closely in appearance and reactions.

Manganese Ethoxide.—A solution containing 3·44 g. of $MnCl_2$,EtOH (above) in 30 c.c. of dry absolute alcohol was run into a sodium ethoxide solution obtained by dissolving 0·92 g. of clean sodium in 20 c.c. of dry ethyl alcohol in a flask protected from the atmosphere. The mixture was shaken, and kept for 24 hours, so that the precipitate of sodium chloride separated. The supernatant liquid was drawn off and allowed to evaporate slowly in a vacuum desiccator until dark brown crystals separated. These were collected and replaced in the desiccator for several days (Found : C, 32·8; H, 7·2; Mn, 37·6. Calc. for $C_4H_{10}O_2Mn$: C, 33·1; H, 6·9; Mn, 37·9%). The ethoxide reacted very readily with water, forming alcohol and white manganese hydroxide, which darkened on exposure to air. The compound was insoluble in ether but dissolved slightly in dry alcohol; the addition of even a trace of water, however, caused the separation of manganese hydroxide. When heated in air, the compound ignited, leaving a black residue. When it was heated out of contact with air, some ether appeared to be evolved, leaving a dark brown residue.

Manganese iso*Propoxide.*—This substance was similarly prepared by adding 3·72 g. of $MnCl_2,C_3H_7OH$ in 30 c.c. of *iso*propyl alcohol to a sodium *iso*propoxide solution (0·92 g. Na; 20 c.c. $Pr^{\beta}OH$). The filtrate, on slowly evaporating, left crystals of *manganese* iso*propoxide* (Found : C, 41·9; H, 8·4; Mn, 31·0. $C_6H_{14}O_2Mn$ requires C, 41·6; H, 8·1; Mn, 31·8%), which resembled the ethoxide in its behaviour towards water and acids, reacting vigorously with them. The alcoholic solution gave no precipitate either with manganese halides or with sodium ethoxide or *iso*propoxide.

Rhenium Triethoxide.—This was obtained as a dark brown solid by the interaction of 1·46 g. of rhenium trichloride in ether with a dry alcoholic solution of sodium ethoxide (0·34 g. Na; 30 c.c. EtOH). The filtrate, on evaporation, left the *ethoxide* (Found : C, 21·8; H, 4·4; Re, 58·7. $C_6H_{15}O_3Re$ requires C, 22·46; H, 4·68; Re, 58·1%). The compound was readily decomposed by water and by dilute acids and alkalis, alcohol and rhenium sesquioxide being first formed in each case. The substance was stable in dry air. On being heated in air it ignited, the black residue first formed gradually burning away. When heated out of contact with air, it began to decompose below 100°, impure rhenium remaining.

*Rhenium Tri*iso*propoxide.*—This light brown solid (Found : Re, 50·8. $C_9H_{21}O_3Re$ requires Re, 51·3%) was obtained similarly to the ethoxide (1·46 g. $ReCl_3$ in ether; 0·34 g. Na in 30 c.c. $Pr^{\beta}OH$), which it resembled in its properties. Hydrolysis with water produced *iso*propyl alcohol and rhenium sesquioxide. Dilute nitric acid also caused the separation of this oxide, but on being warmed with more acid, the precipitate dissolved to give a solution of per-rhenic acid.

The author is indebted to the Chemical Society for a research grant which has partly defrayed the cost of this investigation.

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* Average of estimations as $ReO_2,2H_2O$ and as nitron per-rhenate.

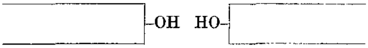
290. *An X-Ray and Thermal Examination of the Glycerides. Part III. The αα'-Diglycerides.*

By Thomas Malkin, Mostafa Riad el Shurbagy, and (in part) Melville L. Meara.*

Continuing our study of the polymorphism of glycerides, we have now investigated a series of αα'-diglycerides, from αα'-didecoin to αα'-distearin, by means of *X*-rays and cooling and heating curves. Apart from their polymorphism, interest attaches to the αα'-diglycerides, as intermediates in the synthesis of the naturally occurring mixed triglycerides of the type $CH_2(OR)\cdot CH(OR')\cdot CH_2\cdot OR$, and it is important that satisfactory criteria of purity should be established.

The polymorphism of the αα'-diglycerides is similar to that of the tri- and mono-glycerides, but the transitions between the various forms are more rapid. An unusual discontinuity occurs at αα'-dipentadecoin, the lower members resembling more the α-monoglycerides, and the higher members resembling the triglycerides. Thus, three modifications exist for αα'-didecoin to αα'-dipentadecoin (α, β', and β) and two modifications exist for αα'-dipalmitin to αα'-distearin (α and β).

The *X*-ray data favour the view that the crystals are built up of layers of double molecules, with the two hydrocarbon chains lying parallel on the same side of the glycerol molecule, *i.e.*,



αα'-Diglycerides have frequently been prepared as intermediates in the synthesis of mixed triglycerides, but the only systematic study of them is that due to Averill, Roche, and King (*J. Amer. Chem. Soc.*, 1929, **51**, 869), who, in the course of a comprehensive investigation of glycerides, revised the earlier unsatisfactory m. p. data for αα'-di-laurin, -myristin, -palmitin, and -stearin. Their revision is not, however, wholly satisfactory, since the recorded m. p.'s fall on an unusually irregular curve. Moreover, no reference is made to the polymorphism (" double melting ") indicated by the observations of earlier workers, *e.g.*, Grün and Theimer (*Ber.*, 1907, **40**, 1798).

We have therefore examined a series from αα'-di-decoin to αα'-distearin, in the manner previously described for the triglycerides (Part I; Clarkson and Malkin, J., 1934, 666) and the α-monoglycerides (Part II; Malkin and Shurbagy, 1936, 1628). We find that, like the tri- and α-mono-glycerides, the αα'-diglycerides exhibit polymorphism. Besides the stable crystalline form obtained from solvents (β-form), all exist in a lower-melting metastable form (probably an α-form). Further, the lower members of the series (C_{10}—C_{15}) exist in a second metastable form of intermediate m. p. (β'-form). When the molten αα'-diglyceride is cooled, the α-form separates first, and rapidly changes into the β'-form (lower members), or the β-form (higher members). The β'-form then changes into the β-form. The transitions are thus very similar to those of the tri- and α-mono-glycerides, but are appreciably quicker, and there is a noticeably greater tendency for the αα'-diglycerides to pass into their stable crystalline form.

An interesting property of the αα'-diglycerides, not previously recorded, is illustrated by Figs. 4 and 5, Plate I. The molten diglyceride is allowed to cool on a microscope slide under a cover slip, and viewed between crossed nicols. Typical spherulite crosses appear, distinguished from those given by triglycerides (Part I, *loc. cit.*) by the circular ripples, brought out more clearly in the higher magnification of Fig. 5. This effect is only observed when the αα'-diglycerides are pure, and best results are obtained with the following gradation in the rate of cooling: αα'-didecoin to αα'-ditridecoin cooled to 0—10°, αα'-dimyristin to αα'-dipentadecoin cooled to room temperature, αα'-dipalmitin to αα'-distearin cooled to between room temperature and 40°.

The αα'-diglycerides used in the investigation were prepared by esterifying α-monoglycerides (Part II, *loc. cit.*), either with fatty acids in the presence of *p*-toluene- or camphor-sulphonic acid, or with acid chlorides in the presence of pyridine. Fischer's method (*Ber.*,

* **M. L. Meara prepared and examined αα'-didecoin and also elaborated the method of preparation of αα'-diglycerides *via* acid chlorides.**

1920, **53**, 1621) does not offer any advantage in yield or technique, and was not adopted on account of the expensive starting material.

Thermal Examination.—This was carried out as described for triglycerides and monoglycerides (*locc. cit.*). Cooling and heating curves were obtained, and the points of arrest checked against capillary m. p. determinations. The curves shown in Fig. 1 for αα'-dilaurin are typical for the lower members (up to αα'-dipentadecoin).

No special feature appears on the cooling curve, which is of a normal type, showing only one arrest (α-form); but two arrests, at higher temperatures, appear on the heating curve (β'- and β-forms). Expected variations in the form of the curves occur, dependent on the rate of cooling and on the length of the hydrocarbon chains. Thus, after a small cooling gradient, the first arrest on the heating curve is much smaller than the second (*i.e.*, the transition β' ⟶ β is more complete). Conversely, after rapid cooling, there are indications on the heating curve of a slight arrest at the m. p. of the α-form, and the first upper arrest is greater than the second (*i.e.*, the transition α ⟶ β' is not complete and the transition β' ⟶ β is slight). These variations, obtained by rapid cooling, are the same as those due to increasing length of hydrocarbon chain, the speed of the transitions being retarded in each case. With αα'-dipalmitin, -diheptadecoin, and -distearin, we found no arrest corresponding to the β'-form. Two arrests are usually observed on the heating curve, but the first always corresponds to that on the cooling curve (α-form).

FIG. 1.

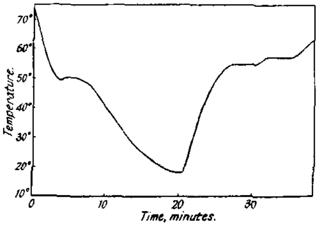
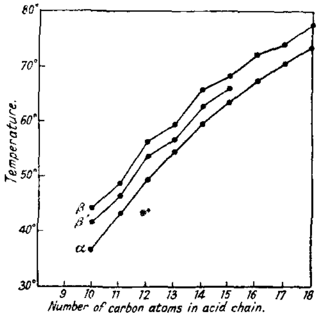


FIG. 2.



Melting points of αα'-diglycerides.

Experiments in capillary tubes confirm the above results. When, for example, αα'-dilaurin is melted in a capillary tube, cooled rapidly (ice), and then heated in the usual manner for a m. p. determination, there is first a change in appearance, accompanied by an increase in volume, slightly below the m. p. of the α-form, and a slight softening at the α m. p. On raising the temperature, there is partial melting at the m. p. of the β'-form, and finally complete melting at the β m. p.

With higher members (αα'-dipalmitin upwards) there is no evidence of a β' m. p. Occasionally complete melting may occur at the α m. p., but generally the transitions are too rapid for the typical "double melting" of triglycerides to be observed (*i.e.*, complete melting followed by resolidification at a higher temperature).

M. p.'s of β'-forms are accurately determined as follows. After a normal capillary m. p. determination, the specimen is allowed to cool slowly in the apparatus, and the nuclei which form in the neighbourhood of the α m. p. are allowed to grow until about a third of the liquid has solidified. If now the temperature is slowly raised, the solid melts at the β' m. p. A few trials may be necessary, in order to judge conditions for avoiding transition into the stable β-form. Provided that the initial temperature of the molten diglyceride

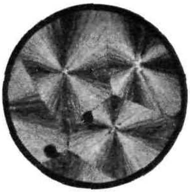


Fig. 4.

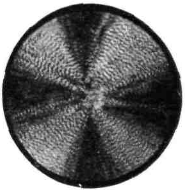


Fig. 5.

$\alpha\alpha'$-*Dimyristin*

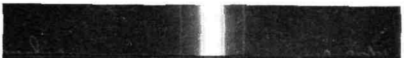


Fig. 6.

$\alpha\alpha'$-*Dilaurin*

Fig. 7.

Typical long spacings.

a-Type

Fig. 8.

b-Type

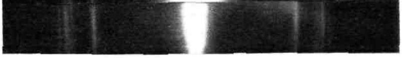


Fig. 9.

Side spacings.

[*To face p.* 1410.

does not greatly exceed the β m. p., the temperature at which nuclei first appear agrees closely with the α m. p. Otherwise, supercooling may occur.

The change in appearance below the α m. p., mentioned above for αα'-dilaurin, suggests that a vitreous form is produced by rapid cooling. The effect is more noticeable for higher members, but in no case was melting observed below the α m. p. The m. p.'s for the series investigated are given in Table I and plotted in Fig. 2. The m. p.'s in the last column, denoted by "A. R. & K.," are those of Averill, Roche, and King (*loc. cit.*).

TABLE I.

Melting points of αα'-diglycerides.

	α.	β'.	β.	A. R. & K.		α.	β'.	β.	A. R. & K.
αα'-*Didecoin* ...	37°	42°	44·5°		αα'-*Dipentadecoin*	63·5°	66·5°	68·5°	
αα'-*Diundecoin*	43·5	47	49		αα'-Dipalmitin ...	68	—	72·5	69·5°
αα'-Dilaurin ...	49·5	54	56·5	56·6°	αα'-*Diheptadecoin*	71·5	—	74·5	
αα'-*Ditridecoin*	54·5	57	59·5		αα'-Distearin	74	—	78	79·1
αα'-Dimyristin	60	63	65·5	63·8—64·4					

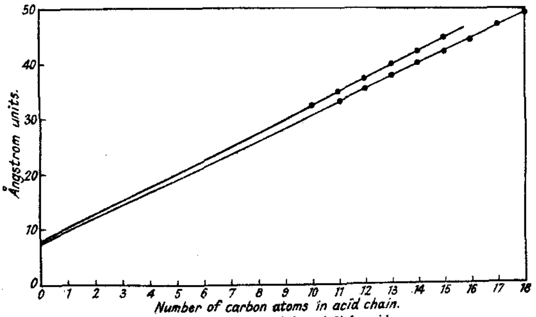
X-Ray Examination.—This was carried out as described in Parts I and II, pressed and melted layers, and rods being examined. Long spacings are given in Table II and plotted in Fig. 3. Typical photographs showing the intensity distribution are reproduced in Plate I, Figs. 6 and 7. The suffix letters *a* and *b* denote the associated side spacings, of which two types were found (Plate I, Figs. 8 and 9), *viz.*,

TABLE II.

Long spacings (A.) *of αα'-diglycerides.*

No. of C atoms in acid	10	11	12	13	14	15	16	17	18
Pressed layer (stable β-form)	32·5*a*	35·2*a*	37·4*a*	40·4*a*	42·6*a*	45·0*b*	44·7*a*	47·7*b*	49·5*a*
Melted layer (β'- or β-form)	32·5*a*	33·2*b*	35·7*b*	38·1*b*	40·5*b*	42·5*b*	44·7*a*	47·7*b*	49·5*a*

FIG. 3.



Long X-ray spacings of the αα'-diglycerides.

a, A.	4·6 strong	3·9 strong	3·73 strong	
b, A.	4·6 strong	3·9 weak	3·73 strong	3·6 weak

The long spacings fall on two straight lines and correspond with double molecules tilted at angles of 72° 12' and 66° 30' for the upper and the lower line respectively. The probable arrangement is

$$\begin{array}{ll} \ldots\ldots CH_2{\cdot}CH_2{\cdot}CO{\cdot}O{\cdot}CH_2 & \quad CH_2{\cdot}O{\cdot}CO{\cdot}CH_2{\cdot}CH_2{\cdot}\ldots\ldots \\ \qquad\qquad\qquad\quad CH{\cdot}OH & \quad HO{\cdot}CH \\ \ldots\ldots CH_2{\cdot}CH_2{\cdot}CO{\cdot}O{\cdot}CH_2 & \quad CH_2{\cdot}O{\cdot}CO{\cdot}CH_2{\cdot}CH_2{\cdot}\ldots\ldots \end{array}$$

but a single linear molecule . . . . . $CH_2{\cdot}CH_2{\cdot}CO{\cdot}O{\cdot}CH_2{\cdot}CH(OH){\cdot}CH_2{\cdot}O{\cdot}CO{\cdot}CH_2{\cdot}CH_2$. . . . . would have approximately the same length and intensity distribution. The intercepts on the curves at *O*-carbon atoms, which are a measure of the length occupied by the glycerol groups and the terminal hydrogen atoms of the hydrocarbon chains, slightly favour the former structure, and although this is not altogether conclusive, further support is given by the close similarity of the side spacings to those of the triglycerides, which have a somewhat similar arrangement of the long chains. These spacings (in A.) are (Clarkson and Malkin, *loc. cit.*) :

5·3 weak   4·6 strong   3·9 strong   3·7 strong

We have been unable to obtain either long or side spacings for the modification that we have provisionally termed the α-form. Their non-alternation in m. p. indicates that the chains are arranged vertically between the terminal planes (cf. Malkin, J., **1931**, **1796**), and analogy with long-chain esters and mono- and tri-glycerides makes it probable that they are vertical rotating molecules.

A perplexing feature of our results is the discontinuity at αα′-dipalmitin shown in the *X*-ray spacings and also by the absence of a β′form. From αα′-didecoin to αα′-dipentadecoin, the spacings of the stable β-form and the metastable β′-form lie respectively on the upper and the lower curve, but from αα′-dipalmitin upwards the spacings of the stable crystalline forms lie on the lower curve. Moreover, αα′-dipalmitin and αα′-distearin retain the *a* type of side spacings which for the lower members corresponds with the upper curve. Further, αα′-dipentadecoin gives both long spacings but only the *b* type of side spacings.

We cannot yet offer any convincing explanation of these peculiarities, particularly as this is the first case that we have encountered, but we have recently obtained evidence of similar discontinuities in other series, and the accumulation of further data may provide the explanation.

Experimental.

The αα′-diglycerides were prepared by esterifying α-monoglycerides either with acids in the presence of 1—2% of *p*-toluenesulphonic acid or *d*-camphor-10-sulphonic acid at 130—140°, or by the action of acid chlorides in the presence of pyridine. Both methods give yields of 65—85%, except in the case of αα′-didecoin, where the yield by the first method is poor. A 5—10% excess of α-monoglyceride was used in order to avoid the formation of triglyceride, which can only be separated from αα′-diglyceride with difficulty, excess α-monoglyceride being easily separated by one or two crystallisations from alcohol. Final crystallisations were from light petroleum (diundecoin to ditridecoin) and hexane or hexane–benzene (dimyristin to distearin). It was necessary to crystallise didecoin throughout from alcohol (ice), owing to the separation of a jelly-like α-form on cooling the light petroleum solution. The crystallisation is wasteful and brings down the final yield in this case to 50%. Final crystallisations are conveniently controlled by microscopic examination (Figs. 4 and 5), these effects only being given when the αα′-diglycerides are pure.

In the first method of preparation, it is important, in order to avoid triglyceride formation, not to exceed the temperature limits, but with this precaution there is little to choose between the two methods. A typical preparation by each method is described.

αα′-Distearin.—A mixture of 1·9 g. of α-monostearin, 1·4 g. of stearic acid, and 0·05 g. of *p*-toluenesulphonic acid in a round-bottomed flask, is heated at 120—130° for 5 hours, removal of water being assisted by occasional attachment to the water pump for a few minutes (porous pot). Two crystallisations from alcohol, followed by two from hexane, yield 2·6 g. of crystalline αα′-distearin, m. p. 79°.

αα′Dilaurin.—To a cold solution of 4·15 g. of α-monolaurin in 30 c.c. of dry benzene, are added 3 g. of lauryl chloride and then slowly, with shaking, 1·15 c.c. of pyridine. After standing overnight, the benzene is removed on the water-bath, and the residue taken up in ether, washed free from pyridine, and dried (sodium sulphate). After removal of ether, the residue is crystallised from alcohol (ice) and finally from light petroleum or hexane; yield 5·1 g.; m. p. 56·5°.

Analytical data are given for the following αα′-diglycerides which have not previously been prepared : *αα′-Didecoin* (Found : C, 68·7; H, 11·0. $C_{23}H_{44}O_5$ requires C, 68·9; H, 11·1%); *αα′-diundecoin* (Found : C, 69·8; H, 11·4. $C_{25}H_{48}O_5$ requires C, 70·1; H, 11·2%); *αα′-ditri-*

decoin (Found: C, 71·7; H, 11·9. $C_{29}H_{56}O_5$ requires C, 71·9; H, 11·6%); *αα'-dipentadecoin* (Found: C, 73·3; H, 12·1. $C_{33}H_{64}O_5$ requires C, 73·3; H, 11·9%); *αα'-diheptadecoin* (Found: C, 74·2; H, 11·9. $C_{37}H_{72}O_5$ requires C, 74·4; H, 12·1%).

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UNIVERSITY OF BRISTOL. *Received, July 3rd, 1937.*]

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291. *Heats of Activation in the Mutarotation of Glucose. Part II. Catalysis by Water, Acids, and Bases.*

By GILBERT F. SMITH and (in part) MERCIA C. SMITH.

The catalytic coefficients and heats of activation have been determined for the catalysis of the mutarotation of glucose by water, by three acids, and by four bases. Slight deviations from the Arrhenius equation have been shown to exist for the water-catalysed reaction, but have not been detected in the case of other catalysts.

The results, together with those recorded in Part I, are examined from the point of view of the kinetic theory of reaction velocity, as expressed by the equation $k = PZe^{-E/RT}$. The heats of activation specific to the various catalysts differ only slightly, and the variations in k are thus due, mainly, to changes in P; P ranges from 10^{-4} for water catalysis to nearly 10^4 for hydroxyl-ion catalysis, and for both acid and basic catalysis can be correlated with the corresponding acid and basic dissociation constants by a relation of the form $P \sim$ const. $\times K^n$, where n is constant for a series of catalysts.

In view of the fact that values for $P \gg 1$ have been obtained, the question is raised as to the validity of the assumptions made in the computation of P.

THE study of the influence of temperature on the catalysis of prototropic changes, which commenced with an investigation of the acetone–iodine reaction (J., 1934, **1744**; subsequently denoted by *A*), has now been continued with the mutarotation of glucose. The present paper is concerned with the catalysis of this reaction by water, and by a number of acid and basic catalysts chosen so as to include the greatest possible range of acid and basic strengths. The mechanism of the reaction in alkaline solutions, which constituted a separate problem, has already been discussed in Part I (J., 1936, 1824; *B*).

The reaction in pure water was first examined. Although during the past 90 years numerous values for the velocity of mutarotation in water have been recorded for temperatures between 0° and 40°, the reliability of many of these is questionable, and at several temperatures serious discrepancies exist between the individual values. It was, in fact, not possible from the existing data to fix the velocity with certainty for any temperature except perhaps for 20°. A number of measurements have therefore been made

The velocity of mutarotation of glucose in water.

Temp.	$10^3 V_{obs.}$	$10^3 V_{calc.}$	Diff., % (calc. − obs.).
0°	1·715 (1·68,[1] 1·69[2])	1·74	+1·5
10	5·32	5·24	−1·5
15	8·98	8·85	−1·4
18	12·15 (12·2[3])	12·0	−1
20	14·7 (15·0,[4] 14·6,[5] 15·2[2])	14·7	0
25	24·0 (22·1,[1] 23·9,[6] 25·3[2])	23·9	−0·5
35	59·3	60·0	+1·2

[1] Andrews and Worley, *J. Physical Chem.*, 1928, **32**, 307. [2] Kilpatrick and Kilpatrick, *J. Amer. Chem. Soc.*, 1931, **53**, 3698. [3] Brönsted and Guggenheim, *ibid.*, 1927, **49**, 2554. [4] Riiber, *Ber.*, 1922, **55**, 3132; 1923, **56**, 2185. [5] Richards, Lowry, and Faulkner, J., 1927, 1733. [6] Kuhn and Jacob, *Z. physikal. Chem.*, 1924, **113**, 389.

at temperatures between 0° and 35°. The velocities obtained, expressed in the units min.$^{-1}$ and logarithms to the base e, are given in col. 2 of the foregoing table. For each

temperature the result given, which is the mean of those obtained in several experiments, was reproducible to about 0·5%. For comparison, there are included in the table velocities recently obtained by other workers, after conversion, where necessary, into the units given above.

It will be seen that for 18°, 20°, and 25° certain previous results are confirmed, but that for 0° the present value is slightly higher than those hitherto recorded. The heat of activation calculated from these figures is not constant over the whole range of temperature, but decreases from 17,160 cals. for the range 18—0° to 16,660 cals. for the range 35—18°. The reaction does not, therefore, conform exactly to the Arrhenius equation, and the extent of the deviations can be seen from the figures given in col. 3 of the table, which are calculated by means of the equation $\log_{10}k = 10{\cdot}785 - 16{,}900/2{\cdot}3026RT$. It will be observed that there is a maximum divergence between the observed and calculated velocities of about $\pm$ 1·5%, which is definitely greater than the experimental error. The deviations from the Arrhenius equation, although small, are thus considered to be real.

Previous investigations have failed to detect these slight irregularities, presumably because they were masked by a rather larger experimental error. An exception is the experiments of Hudson and Dale (*J. Amer. Chem. Soc.*, 1917, **39**, 320). Below are given heats of activation derived from their data for temperatures above and below 20°. These have been calculated, for intervals of not less than 10°, from the mean velocities for α- and β-glucose at each temperature.

Temp.	*E*.	Temp.	*E*.
20°/0·7°	17,900	40°/20°	17,000
20°/5°	16,500	40°/25°	16,700
20°/10°	17,400	40°/30°	16,700
Mean	17,300	Mean	16,800

It is clear that, on the average, *E* is decidedly greater over the lower temperature range, which is in harmony with our own conclusion. On the other hand, this view is at variance with the more recent work of Moelwyn-Hughes, Klar, and Bonhoeffer (*Z. physikal. Chem.*, **1934**, *A*, **169**, 113), who conclude, as the result of measurements at four temperatures between 9·58° and 39·86°, that the reaction follows the Arrhenius equation with an accuracy which is better than 1%, *i.e.*, within the experimental error. This work is, however, open to criticism on experimental grounds. The velocity they obtained for 19·65°, expressed in the units here adopted, is 0·0149, which on the basis of their own results, can be shown to correspond to 0·0154 at 20°. This value is undoubtedly too high, as is shown by the extensive experiments of Lowry (*loc. cit.*) and of Riiber (*loc. cit.*). Lowry, as the result of nine concordant polarimetric determinations, recorded 0·0146, which he regarded as sufficiently accurate to be considered the "standard" value. Riiber's experiments, which were of even greater scope and included polarimetric, dilatometric, and interferometric measurements with both α- and β-glucose and with glucose hydrate, give a mean velocity of 0·0150. Both these results are fairly close to our own, and it can thus be stated with confidence that the correct velocity at 20° is 0·0148 $\pm$ 0·0002. The above value of 0·0154, therefore, represents a discrepancy of about 3%, which obviously invalidates the authors' conclusions.

The mean heat of activation resulting from the present measurements, which is about 17,000 cals., is lower than previous estimates, which range from 17,340 (Euler and Ugglas, *Z. physiol. Chem.*, 1910, **65**, 124) to 17,700 cals. (Hudson and Dale, *loc. cit.*). These differences are, however, more apparent than real, for on the assumption of a constant heat of activation, there is clearly some latitude in fixing its value.

The question which naturally arises is whether the anomalous behaviour observed in the case of the water reaction, persists, or is even accentuated, in the case of other catalysts. A completely unequivocal answer to this question cannot be given. It is found for basic catalysis by hydroxyl ion, glucosate ion (*loc. cit.*, *B*), and phenoxide ion (p. 1417), and for acid catalysis by hydrion (p. 1415) that in each case the reaction conforms to the Arrhenius equation within the limits of experimental uncertainty. This uncertainty is, however, greater than in the case of water, and varies somewhat from catalyst to catalyst. For less

efficient catalysts, small irregularities would escape detection entirely, but there is no reason to suspect a behaviour different from that of the catalysts just enumerated.

Acid Catalysis.—(1) *Hydrion.* The velocity of mutarotation in a solution which was 0·0400*M* with respect to hydrochloric acid was measured at five temperatures. The results are given in Table I. In row 2 are given the observed velocities; in row 3 the partial velocities due to hydrion, obtained by subtracting from the total velocity that due to water; and in row 4 are the velocities due to hydrion, calculated from the equation

$$\log_{10} V_h = 12{\cdot}111 - 18{,}600/2{\cdot}3026RT$$

TABLE I.

Mutarotation of glucose in 0·0400M-*hydrochloric acid.*

Temp.	0°	10°	18°	25°	35°
$10^3 V_{obs.}$	3·33	10·7	25·5	52·8	138·5
$10^3 V_h$	1·615	5·38	13·35	28·8	79·2
$10^3 V_{h,\ calc.}$	1·610	5·41	13·4	28·5	79·2

This equation is seen to give figures which agree with the experimental values within about 1%, which represents the accuracy with which the partial velocity due to hydrion can be evaluated. The value of 18,600 cals. obtained for the heat of activation is intermediate between those given by Kilpatrick and Kilpatrick (*loc. cit.*) and by Moelwyn-Hughes (*Z. physikal. Chem.*, 1934, *B*, **26**, 272), *viz.*, 19,300 and 18,030 cals. respectively. Confirmation of the present result was sought by making additional measurements at 0° and 25° in solutions in which the concentration of hydrochloric acid was varied. The figures are given in Table II. Following previous procedure (*loc. cit.*, *A*), the temperature coefficient for hydrion catalysis was evaluated from the experimental data by the method of reciprocal ratios, since this method minimises errors due to salt effects. The equations given in the paper referred to may be generalised in the form

$$\frac{1}{R_{obs.}} = \frac{1}{R_1} + \frac{{}_{25}V_2}{{}_{25}V_{obs.}}\left\{\frac{1}{R_2} - \frac{1}{R_1}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$= \frac{1}{R_2} - \frac{{}_{25}V_1}{{}_{25}V_{obs.}}\left\{\frac{1}{R_2} - \frac{1}{R_1}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1a)$$

where $V_{obs.}$ is regarded as the sum of velocities V_1 and V_2 due to catalysts 1 and 2 respectively, and the *R*'s have their previous significance. In the present case 1 is hydrion and 2 is water, and on insertion of the experimental constants (1) reduces to

$$1/R_{obs.} = 0{\cdot}0566 + 3{\cdot}65 \times 10^{-4}/{}_{25}V_{obs.}.$$

The values of $1/R_{obs.}$ obtained by means of this equation are given in the last row of the table.

TABLE II.

Mutarotation of glucose in CM-*hydrochloric acid at* 0° *and* 25°.

C	0	0·01	0·02	0·05	0·10
${}_{25}V_{obs.} \times 10^3$	2·40	3·13	3·87	5·98	9·53
$1/R_{obs.}$	0·0714	0·0687	0·0663	0·0624	0·0606
$1/R_{obs.}$, calc.	0·0718	0·0683	0·0660	0·0627	0·0604

$1/R_h$ is thus 0·0566, which gives $E = 18{,}560$ cals., as compared with 18,600 cals. obtained previously, giving a mean of 18,580 cals.

(2) *Chloroacetic acid.* Kinetic measurements were made at 0° and 25° in solutions of chloroacetic acid varying from 0·10 to 0·60*M*. In such solutions the catalysts are water, undissociated chloroacetic acid, hydrion, and, to a much smaller extent, the chloroacetate ion; thus $V_{obs.} = V_{H_2O} + V_m + V_h + V_a$. In applying (1), catalysts 1 and 2 are regarded as chloroacetic acid and water respectively, and $V_{obs.}$ is replaced by $V_{corr.} = V_{obs.} - V_h - V_a$, and $R_{obs.} = {}_{25}V_{corr.}/{}_{0}V_{corr.}$. The data are given in Table III.

The observed velocities at 25° and 0° are given in rows 2 and 3 respectively, and the values of $V_{corr.}$ are derived from them by subtracting the partial velocities due to hydrion and

TABLE III.

Mutarotation of glucose in CM-*chloroacetic acid at* 0° *and* 25°.

C	0	0·100	0·200	0·400	0·600
$10^3 \times {}_{25}V_{obs.}$	24·0	36·6	44·7	58·1	70·8
$10^3 \times {}_{0}V_{obs.}$	1·715	2·45	2·98	3·82	4·62
$10^3 \times {}_{25}V_{corr.}$	24·0	27·9	32·45	40·5	49·1
$10^3 \times {}_{0}V_{corr.}$	1·715	1·97	2·28	2·82	3·39
$1/R_{obs.}$	0·0714	0·0706	0·0703	0·0696	0·06905
$1/R_{obs.}$, calc.	0·0715	0·0707	0·0703	0·0696	0·0691

chloroacetate ion, which have been calculated taking by K_a to be $1·5 \times 10^{-3}$, and the respective catalytic coefficients as 0·72 and 0·021 at 25°, and as 0·041 and 0·0012 at 0°. The resulting values of $1/R_{obs.}$ (row 6) are closely reproduced by those given in row 7, derived from the equation

$$1/R_{obs.} = 0·0668 + 1·12 \times 10^{-3}/{}_{25}V_{corr.}$$

hence $1/R_m = 0·0668$, which gives $E = 17{,}500$ cals.

(3) *Acetic acid.* Precisely similar arguments apply to this case. The results of measurements in solutions of acetic acid ranging from 0·5 to 0·2M are given in Table IV, the arrangement of which is similar to that of Table III. In the calculation of the partial velocities due to hydrion and acetate ion, K_a has been taken as $1·8 \times 10^{-5}$, the catalytic coefficient for hydrion as before, and that for the acetate ion as 0·133 at 25° and 0·0077 at 0°.

TABLE IV.

Mutarotation of glucose in CM-*acetic acid* 0° *and* 25°.

C	0	0·500	1·000	1·500	2·000
$10^3 \times {}_{25}V_{obs.}$	24·0	32·6	39·6	46·9	54·6
$10^3 \times {}_{0}V_{obs.}$	1·715	2·31	2·76	3·27	3·78
$10^3 \times {}_{25}V_{corr.}$	24·0	30·15	36·0	42·5	49·5
$10^3 \times {}_{0}V_{corr.}$	1·715	2·15	2·55	3·02	3·49
$1/R_{obs.}$	0·0714	0·0713	0·0708	0·0710	0·0705
$1/R_{obs.}$, calc.	0·0715	0·0712	0·0710	0·0708	0·0707

The figures given in the last row are derived from the equation

$$1/R_{obs.} = 0·0699 + 3·84 \times 10^{-4}/{}_{25}V_{corr.}$$

from which $1/R_m = 0·0699$, and $E = 17{,}200$ cals.

Basic Catalysis.—(1) ***Phenoxide ion.*** Aqueous solutions containing appreciable amounts of phenoxide ions are sufficiently alkaline to render perceptible catalytic effects due to hydroxyl and glucosate ions, so that for the observed velocity we have $V_{obs.} = V_{H_2O} + V_{OH} + V_G + k_{\phi O}c_{\phi O}$. Since the partial velocities V_{OH} and V_G can be evaluated, a knowledge of $V_{obs.}$ for a series of solutions in which $c_{\phi O}$ is varied, allows of the determination of $k_{\phi O}$. Velocity measurements were made in solutions containing phenol and sodium hydroxide at 0°, 5°, 10°, 15°. Since phenol has an appreciable medium effect on the reaction, its concentration was kept approximately constant throughout. This concentration was made as large as possible in order to diminish catalysis by hydroxyl ions and glucosate ions. The results obtained for 5° are tabulated below.

Mutarotation of glucose in phenol–sodium hydroxide mixtures at 5°.

C_{GH}	$0·715_5$	0·703	0·722	0·733	0·729
$C_{\phi OH}$	0·466	0·461	0·466	0·464	0·466
10^3C_{NaOH}	2·938	9·30	19·24	28·71	38·51
$10^3C_{\phi O}$	2·910	9·210	19·05	28·42	38·12
$10^2V_{obs.}$	1·104	2·69	5·16	7·50	10·0
10^2V_{OH}	0·046	0·15	0·31	0·48	0·65
10^2V_G	0·026	0·08	0·17	0·27	0·36
$10^2V_{corr.}$	1·03	2·46	4·68	6·75	8·99
$10^2V_{corr.}$, calc.	1·03	2·45	4·68	6·80	8·99

In the first row is given the total concentration of glucose, which to a very close approximation is equal to the concentration of free glucose. In rows 2 and 3 respectively are the total concentrations of phenol and sodium hydroxide. In these solutions the hydrolysis

of the sodium phenoxide is very small, and may be neglected in the calculation of the concentration of the phenoxide ion, which thus depends only on the quantities given in rows 1—3 and the ratio of the dissociation constant of glucose to that of phenol, $K_{GH}/K_{\phi OH}$, which has been taken to be $6{\cdot}1 \times 10^{-3}$ at 5°. The value of this ratio, for each of the temperatures employed, has been calculated from the basis that ${}_{20}K_{GH} = 6{\cdot}5 \times 10^{-13}$ (Ölander, *Z. anorg. Chem.*, 1925, **136**, 61) and ${}_{25}K_{\phi OH} = 1{\cdot}1 \times 10^{-10}$ (Lundén, *Z. physikal. Chem.*, 1910, **70**, 249) with respective heats of dissociation of approximately 9500 cals. (*loc. cit.*, *B*) and 7600 cals. (unpublished work). This calculation is sufficiently accurate for the present purpose, since it will be seen that the concentration of phenoxide ion differs from that of the total sodium hydroxide by only about 1%. The partial velocities due to hydroxyl ion and glucosate ion, given in rows 5 and 6, have been obtained by taking the respective catalytic coefficients to be 1,700 and 9·2, and the hydrolysis constant of sodium phenoxide as $4{\cdot}3 \times 10^{-5}$. Values for $V_{obs.} - V_{OH} - V_G = V_{corr.}$ are given in row 7, and are in close agreement with those given in the last row, derived from the equation $V_{corr.} = 0{\cdot}37 \times 10^{-2} + 2{\cdot}26\, C_{\phi O}$. The catalytic coefficient for the phenoxide ion at 5° can thus be stated with some confidence to be 2·26, which is about 30 times greater than that for hydrion at this temperature. Precisely similar relations were found to hold at 0°, 10°, 15°. In col. 2 of the following table are given the catalytic coefficients obtained for each temperature, and in col. 3 the values obtained from the equation

$$\log_{10} k_{\phi O} = 14{\cdot}915 - 18{,}500/2{\cdot}3026RT.$$

Temp.	0°	5°	10°	15°
$k_{\phi O}$	1·225	2·26	4·12	7·22
$k_{\phi O}$, calc.	1·23	2·26	4·10	7·26

For catalysis by phenoxide ions, therefore, the heat of activation is 18,500 cals., and there are no obvious deviations from the Arrhenius equation.

(2) *Secondary phosphate ion.* Measurements were made at 0° and 25° in solutions which contained both primary and secondary phosphates, and had the composition $0{\cdot}05M$-KH_2PO_4 + CM-Na_2HPO_4, the values of C being such that catalysis by hydroxyl ions was negligibly small. The observed velocity is given by the expression $V_{obs.} = V_{H_2O} + V_{H_2PO_4} + V_{HPO_4}$, in which catalysts 1 and 2 of (1) can be regarded as HPO_4'' and $(H_2PO_4' + H_2O)$ respectively. The data are given in the following table, the figures in the last row being calculated from the equation

$$1/R_{obs.} = 0{\cdot}0620 + 1{\cdot}87 \times 10^{-3}/{}_{25}V_{obs.}.$$

Mutarotation of glucose in solutions of composition 0·05M-KH_2PO_4 + CM-Na_2HPO_4 *at* 0° *and* 25°.

$C \times 10^3$	0	2·00	3·00	5·00	10·0	15·0
${}_{25}V_{obs.}$	3·73	4·50	4·88	5·60	7·39	9·07
$1/R_{obs.}$	0·0672	0·0665	0·0660	0·0657	0·0643	0·0642
$1/R_{obs.}$, calc.	0·0670	0·0666	0·0658	0·0653	0·0645	0·0641

Hence for catalysis by the secondary phosphate ion $1/R_a$ is 0·0620, which gives E = 17,800 cals.

(3) *Acetate ion.* Measurements were made at 0° and 25° in solutions of composition $0{\cdot}1M$-acetic acid + CM-sodium acetate. The catalysts are water, acetate ion, and undissociated acetic acid, and similar reasoning applies to that in (2). The results are tabulated below.

Mutarotation of glucose in mixtures of composition 0·1M-*acetic acid* + CM-*sodium acetate at* 0° *and* 25°.

C	0	0·0391	0·0781	0·150	0·250	0·400
$100\,{}_{25}V_{obs.}$	2·53 *	3·12	3·59	4·59	5·89	7·74
$1/R_{obs.}$	0·0713 *	0·0686	0·0680	0·0662	0·0644	0·0636
$1/R_{obs.}$, calc.	0·0716	0·0689	0·0679	0·0660	0·0646	0·0635

* Derived from the data in Table IV.

The numbers in the last row are calculated from the equation

$$1/R_{obs.} = 0{\cdot}0598 + 2{\cdot}84 \times 10^{-4}/{}_{25}V_{obs.}$$

thus giving 0·0598 for $1/R_a$, which gives $E = 18{,}200$ cals. This is probably more accurate than the substantially higher value of 19,100 cals. given by Kilpatrick and Kilpatrick.

(4) *Chloroacetate ion.* The procedure was similar to that in (3) above. In this case there is just detectable catalysis by hydrion, but provided $V_{\text{obs.}}$ is replaced by $V_{\text{corr.}} = V_{\text{obs.}} - V_h$, the argument is unchanged. The figures in the last row of the following table are calculated by means of the equation

$$1/R_{\text{obs.}} = 0{\cdot}0578 + 3{\cdot}70 \times 10^{-4}/{}_{25}V_{\text{corr.}}.$$

Hence for catalysis by the chloroacetate ion $1/R_a = 0{\cdot}0578$ and $E = 18{,}400$ cals.

Mutarotation of glucose in mixtures of composition 0·1M-*chloroacetic acid* + CM-*sodium chloroacetate at* 0° *and* 25°.

C	0	0·300	0·400	0·500	0·700
$100_{25}V_{\text{obs.}}$	—	3·63	3·83	4·06	4·47
$100_0V_{\text{obs.}}$	—	0·247	0·259	0·272	$0{\cdot}292_5$
$100_{25}V_{\text{corr.}}$	2·82 *	3·59	3·80	4·04	4·45
$100_0V_{\text{corr.}}$	0·199 *	0·245	0·257	0·271	0·292
$1/R_{\text{obs.}}$	0·0707 *	0·0682	0·0676	0·0670	0·0657
$1/R_{\text{obs.}}$, calc.	0·0707	0·0682	0·0676	0·0669	0·0661

* Derived from the figures in Table III.

Discussion.

On the evidence available it appears to be legitimate to formulate the chemical reactions giving rise to the mutarotation of glucose in either of two ways, *viz.*, (1) $\alpha \underset{v_\beta}{\overset{v}{\rightleftarrows}} \beta$ in which the two forms of the sugar are directly interconverted, and (2) $\alpha \underset{v_2}{\overset{v_1}{\rightleftarrows}} \mu \underset{v_4}{\overset{v_3}{\leftrightarrows}} \beta$ in which the interconversion takes place *via* an intermediate form, μ, which can be regarded as an open-chain compound. The significance to be attached to the measured unimolecular velocity coefficient, $V_{\text{obs.}}$, differs according to which of these formulations is accepted. It follows from (1) that $V_{\text{obs.}} = V_\alpha + V_\beta$ and the individual velocity coefficients V_α and V_β can be derived from a knowledge of the equilibrium constant, which as deduced from the rotatory powers of the α- and the β-sugar and that of the equilibrium mixture has the value 0·56, independently of temperature (Nelson and Beegle, *J. Amer. Chem. Soc.*, 1919, **41**, 570); hence $V_\alpha = V_{\text{obs.}}/1{\cdot}56$ and $V_\beta = V_{\text{obs.}}/2{\cdot}8$. On the other hand, on the basis of scheme (2), $V_{\text{obs.}} = V_1 = V_3$ (Smith and Lowry, J., 1928, 666), *i.e.*, $V_{\text{obs.}}$ is simply the rate at which either the α- or the β-form undergoes the prototropic change resulting in the production of the intermediate. This is the view adopted in the present paper, but this must not be taken to imply that it is considered possible to decide definitely between the alternative schemes. On the contrary, there is a certain ambiguity in the interpretation of the results, but from the foregoing it will be seen that, in all probability, this can be represented by a numerical factor of not more than about 3. This uncertainty cannot, therefore, be the reason for the apparently anomalous results obtained for certain catalysts, since, as shown later, the factor involved in these cases is one of several powers of 10, which is of a different order of magnitude.

The results are summarised in the following table, which includes the data given in

	k.	E (cals.).	$Z \times 10^{13}$.	P.	P, calc.	$K_b = 1/K_a$.
Basic catalyst.						
Hydroxyl ion	$9{\cdot}3 \times 10^2$	17,700	1·7	$8{\cdot}2 \times 10^3$	$16{\cdot}0 \times 10^3$	* $1{\cdot}5 \times 10^{16}$
Glucosate ion	5·2	17,000	1·2	$1{\cdot}8 \times 10^1$	42×10^1	$3{\cdot}1 \times 10^{12}$
Phenoxide ion	$1{\cdot}22_5$	18,500	1·4	$5{\cdot}8 \times 10^1$	$4{\cdot}8 \times 10^1$	$1{\cdot}6 \times 10^{10}$
HPO_4'' ion	$2{\cdot}5 \times 10^{-1}$	17,800	1·1	4·1	2·7	$1{\cdot}6_5 \times 10^7$
Acetate ion	$7{\cdot}7 \times 10^{-3}$	18,200	1·4	$2{\cdot}1 \times 10^{-1}$	$2{\cdot}5 \times 10^{-1}$	$5{\cdot}6 \times 10^4$
Chloroacetate ion	$1{\cdot}2 \times 10^{-3}$	18,400	1·2	5×10^{-3}	$3{\cdot}9 \times 10^{-3}$	$6{\cdot}7 \times 10^2$
Water	$3{\cdot}09 \times 10^{-5}$	17·000	1·7	1×10^{-4}	$4{\cdot}7 \times 10^{-4}$	$1{\cdot}8 \times 10^{-2}$
Acid catalyst.						K_a.
Hydrion	$4{\cdot}1 \times 10^{-2}$	18,580	1·7	1·6	1·9	† $5{\cdot}55 \times 10^1$
Chloroacetic acid	$2{\cdot}8 \times 10^{-3}$	17,500	1·2	$2{\cdot}5 \times 10^{-2}$	$2{\cdot}3 \times 10^{-2}$	$1{\cdot}5 \times 10^{-3}$
Acetic acid	$8{\cdot}9 \times 10^{-4}$	17,200	1·4	$3{\cdot}7 \times 10^{-3}$	$3{\cdot}7 \times 10^{-3}$	$1{\cdot}8 \times 10^{-5}$

* Calculated from $P = 2{\cdot}5 \times 10^{-3} \times K_b^{0{\cdot}43}$. † Calculated from $P = 0{\cdot}36 \times K_a^{0{\cdot}43}$.

Part I for hydroxyl-ion and glucosate-ion catalysis. The catalytic coefficients for 0° (col. 2) are derived from the figures given in the tables, and refer to zero salt concentration. The catalytic coefficient for water is taken as $V_{H_2O}/55{\cdot}5$, and should be roughly comparable with the others.

In considering the results from the point of view of the kinetic equation $k = PZe^{-E/RT}$, a complication is apparent in that for one catalyst, and possibly for others, E is not entirely independent of temperature. This, however, is to be anticipated on quantum-mechanical grounds in certain circumstances (Bell, *Proc. Roy. Soc.*, 1936, *A*, **154**, 414), and it is presumably permissible to regard E as representing a mean value for the temperature range considered. On this assumption, the values for P given in col. 5 have been derived, Z being calculated from the formula for binary collisions in a gas. It will be seen that P varies from 10^{-4} for water catalysis to nearly 10^4 for hydroxyl-ion catalysis. Both the absolute magnitudes attributed to P, and the variations in P, represented by a factor of about 10^8, are remarkable.

In this latter connection, it is found that P, for both acid and basic catalysis, is connected with the corresponding acid or basic dissociation constant by an approximate relation of the form previously established in the case of the acetone–iodine reaction (*loc. cit.*; *A*), *viz.*

$$P \sim \text{const.} \times K^n \qquad (2)$$

where n is constant for a series of catalysts. The calculated values of P are given in col. 6, and have been derived from the equations given at the foot of the table. In applying the equations, it is sufficiently accurate to regard K_a and K_b as independent of temperature, except in the case of the strong bases, for which K_b has been taken for the temperature intermediate between those to which the heat of activation refers. For the basic catalysts, the relation holds within a factor of 5, except in the case of the glucosate ion, where the deviation is much greater. Too much significance should not, however, be attached to this discrepancy for it is by no means certain that the glucosate ion is strictly comparable with the other catalysts, for it obviously occupies a unique position, in that, besides being a base, it is also the ion of the reacting substance. In fact, in this case, it would not be possible to differentiate between the catalytic activity of the ion and its reactivity. For the acid catalysts the series is much less extensive, but is sufficient to establish the relation given above.

The position occupied by water calls for comment. As would be anticipated, water functions as a base, and it is found to have a P value very close to that required by its basic strength. This value is obtained on the assumption that E and Z can be calculated precisely as for the other catalysts, *i.e.*, without the correction for viscosity. On the other hand, if the viscosity correction is applied P becomes approximately unity (Moelwyn-Hughes, " The Kinetics of Reactions in Solution," 1933, p. 233), but this places water in an entirely anomalous position, since it is then quite unrelated to either series of catalysts. In the present case, therefore, the application of the viscosity correction does not appear to be warranted.

It has been pointed out previously that if (2) applies, then $k \sim \text{const.} \times K^nZe^{-E/RT}$. This is clearly not open to question, and in this connection the recent criticism of Moelwyn-Hughes (*Acta Physicochim.*, 1936, **4**, 173) is irrelevant, since it is, in actual fact, directed against an incorrectly quoted version of this expression. The above relation could be interpreted as indicating that for values of $P \lesssim 1$, the probability of an activated collision being effective is limited by the probability of the simultaneous transfer of a proton to, or from, the catalyst molecule. Values of $P \gg 1$, as are obtained in the present instance, cannot, however, have the same significance, and are, indeed, open to suspicion in a reaction considered to be essentially bimolecular. It is therefore necessary to re-examine the bases on which the calculations have been made.

In the first place the question arises as to the validity of applying the gas-collision formula to liquid media. This has been criticised by Bradley (J., 1934, 1910) and by Evans and Polanyi (*Trans. Faraday Soc.*, 1936, **32**, 1333), but the large amount of data now available certainly suggests that the error thereby introduced does not exceed one or two powers of 10, and it would be surprising if it were as large as 10^4. It therefore seems

improbable that the large P values are to be attributed entirely to the incorrect computation of Z.

A more likely possibility is that the heat of activation, as evaluated from the temperature coefficient, is not the true value. This could arise through a failure to take cognisance of some temperature-variable factor, thus preventing a complete separation of the two terms of the Arrhenius equation. Such a factor, it might be suggested, is the acid or basic strength of the catalyst, which is related to the catalytic coefficient by the well-known Brönsted equation, $\log k = \log G + n . \log K$, where G and n are constants. It follows that

$$d\log k/dT = d\log G/dT + n . d\log K/dT + dn/dT . \log K,$$

which, if G varies exponentially with temperature, gives

$$E_{obs.} = E' + nQ + RT^2 . dn/dT . \log K.$$

Provided dn/dT be small, the heat of activation at constant acid or basic strength is then $E_{obs.} - nQ$ (compare Pedersen, *J. Physical Chem.*, 1934, **38**, 601). This condition holds for the basic catalysis, where n has the values 0·41 at 0° and 0·42 at 25°. The figures are given in the following table, where the values of Q are those given by Harned and Hamer (*J. Amer. Chem. Soc.*, 1933, **55**, 2184) and by Harned and Umbree (*ibid.*, 1934, **56**, 1050) for 10°, except for the glucosate and phenoxide ions, where approximate data are available for 20° only.

Basic catalysis of mutarotation.

Catalyst.	$E_{obs.}$.	Q.	$E_{obs.} - nQ$ (cals.).	Catalyst.	$E_{obs.}$.	Q.	$E_{obs.} - nQ$ (cals.).
Hydroxyl ion	17,700	14,200	23,400	Acetate ion	18,200	289	18,360
Glucosate ion	17,000	9,500	20,800	Chloroacetate ion	18,400	−593	18,200
Phenoxide ion	18,500	7,600	21,500	Water	17,000	0	17,000
HPO_4'' ion	17,800	1,230	18,290				

The figures in the last col. show that the effect of this correction is to increase materially the heats of activation just for those catalysts for which P is already too large, and the result is thus to accentuate rather than to diminish the existing discrepancy. The preceding argument is therefore of doubtful value, and further, since no simple relation of any sort exists between Q and $E_{obs.}$, it is very improbable that Q is a quantity of any real significance in this connection.

Finally, it is not impossible that internal degrees of freedom of the glucose molecule are involved in the activation, but there are obvious difficulties in the application of such an hypothesis to account for the results as a whole. We are therefore at present unable to explain our P values in any plausible manner in terms of the kinetic theory of reaction velocity. If the experimental results are accepted, however, they indicate clearly that in a reaction involving solely a prototropic change, either E or Z cannot be evaluated in the customary manner.

Velocity Measurements.—The procedure was as described previously (*loc. cit.*; *B*), except that only in the case of phenoxide-ion catalysis was it necessary to maintain the rigid precautions to exclude atmospheric carbon dioxide from the experimental solutions.

Materials.—With the exception of chloroacetic acid, these were of AnalaR grade, and they were purified either by crystallisation from water, or by fractional freezing to constant f. p.

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292. *Studies of the* ortho-*Effect. Part I. The Influence of Substituents in the* ortho-*Position upon the Chemical Characters of Carboxylic Acids and their Derivatives.*

By J. F. J. Dippy, D. P. Evans, J. J. Gordon, R. H. Lewis, and H. B. Watson.

In this series of papers, an attempt is made to throw further light upon the peculiar effects of groups in the *o*-position upon reactivity and upon the strengths of acids and bases. Victor Meyer's conception of steric hindrance does not provide a complete explanation of the observed phenomena, although a geometrical effect of this character cannot be neglected as a possible contributory factor, while in some cases it may be the most important cause. It is significant, however, that the *ortho*-effect appears to operate only when the reacting group contains an electron-donating atom (*e.g.*, $-COR$, $-NR_2$), and a consideration of available evidence, together with some new results recorded in the two following papers, leads to the conclusion that in many carboxylic acids and derivatives there may be an interaction of the *o*-substituent with the unshared electrons of this group to form a hydrogen bond or a co-ordinate linkage as visualised by Sidgwick and Callow in their consideration of the physical properties of *o*-substituted phenols. Certain difficult examples are shown to be not inconsistent with this view. At the same time, the probable intervention of other factors is fully realised.

The relative inertness of many *o*- and di-*o*-substituted benzene derivatives has frequently been demonstrated in reactions such as the formation of quaternary ammonium salts by anilines and of oximes and phenylhydrazones by ketones, the esterification of carboxylic acids, and the hydrolysis of esters, nitriles, acid chlorides, and amides (see summary in Cohen, "Organic Chemistry," Vol. 1, Ch. V). The usual polar effects of substituents will operate from the *o*-position not less than from the *p*-position, but in the *o*-substituted compounds there is evidence of some additional factor which is absent in the isomeric derivatives.

In the course of an extensive series of investigations (for summary and refs., see Lloyd and Sudborough, J., 1899, **75**, 580), Victor Meyer, Sudborough, and their collaborators found that di-*o*-substituted benzoic acids gave no ester when their alcoholic solutions were saturated with hydrogen chloride at 0° or treated by the Fischer–Speier method; even when the boiling solutions were saturated with hydrogen chloride for prolonged periods, the esterification was either not detectable (with NO_2, Cl, Br, or I as substituents) or very slight (with alkyl groups, OH, or F). Moreover, the esters and other derivatives of these acids were unusually stable to hydrolytic agents. The retardation of esterification and hydrolysis by one *o*-substituent was also demonstrated (compare also Goldschmidt, *Ber.*, 1895, **28**, 3218; Kellas, *Z. physikal. Chem.*, 1897, **24**, 221; Kindler, *Annalen*, 1928, **464**, 278). Analogous effects in aliphatic compounds are illustrated by the order of velocities $CH_3{\cdot}CO_2H > CH_2X{\cdot}CO_2H > CHX_2{\cdot}CO_2H > CX_3{\cdot}CO_2H$ for the esterification of *all* series of substituted acetic acids independently of the nature of X (Sudborough and Lloyd, J., 1899, **75**, 467) and the different rates of esterification of *cis*- and *trans*-substituted acrylic acids (Sudborough *et al.*, J., 1898, **73**, 81; 1905, **87**, 1840). The strengths of aromatic acids and bases are also profoundly influenced by substituents in the *o*-position, and analogies are found in phenomena such as the greater strength of *allo*cinnamic than of cinnamic acid (compare Dippy and Lewis, this vol., p. 1008). The classical dissociation constants of Ostwald and others indicate that *all* *o*-substituted benzoic acids are stronger than benzoic itself, and often very considerably stronger than their *m*- and *p*-isomerides; this is confirmed by recently measured thermodynamic constants, a table of which, referred to $K_{therm.}$ for benzoic acid as unity, is included in Part II (following paper). Very few values for di-*o*-substituted benzoic acids are available, but in at least two cases (2 : 6-dihydroxy- and 2 : 6-dinitro-) the presence of the second *o*-substituent leads to a further large increase in the dissociation constant. Groups in the *o*-position decrease the strengths of anilines,

and confer increased stability upon benzaldehydecyanohydrins (Lapworth and Manske, J., 1928, 2533).

Meyer emphasised the fact that the *ortho*-effect does not depend upon the chemical nature of the substituent (thus, *o*-F is not comparable with the other halogens), but appears rather to be governed by its size (as measured, according to him, by the weights of the atoms). Moreover, the effect does not operate if the reacting group is separated from the nucleus by one or more carbon atoms (as, *e.g.*, in mesitylacetic acid); this has been confirmed more recently by measurements of the strengths of phenylacetic acids (Part II) and of the rates of hydrolysis of cinnamic esters (Kindler, *loc. cit.*). The conception of steric hindrance was based upon observations of this type. There is, however, no definite relationship, even of a qualitative nature, between the influence of a group in the *o*-position and its weight or volume (*e.g.*, NO_2 is usually more effective than I). Flürscheim (J., 1909, **95**, 725) interpreted the relatively high dissociation constants of *o*-substituted acids in the light of Meyer's theory, and his suggestion, when modified in accordance with present views of ionisation, may be expressed by saying that since, in the equilibrium $R{\cdot}CO_2H + H_2O \rightleftharpoons R{\cdot}CO_2^{\ominus} + H_3O^{\oplus}$ (in dilute aqueous solution) the acid is in continual contact with water molecules, steric hindrance will not influence the ionisation perceptibly but will retard the reassociation process. Applied to the equilibrium $R{\cdot}NH_2 + H_2O \rightleftharpoons R{\cdot}NH_3^{\oplus} + OH^{\ominus}$, however, this would lead to the expectation of increased strength in *o*-substituted bases, for here again only the reversed change will be influenced unfavourably; actually a marked decrease in strength is observed. While, therefore, steric hindrance in the Victor Meyer sense may frequently be an important factor (compare also the restricted rotation in *o*-substituted diphenyls and analogous compounds), the problem of the *ortho*-effect is one of great complexity, and the observations cannot be explained completely in terms of a purely geometrical effect (compare Davis, J., 1900, **77**, 33; Kindler, *loc. cit.*). The work to be described in this series of communications has been undertaken in an attempt to trace the origin of the *ortho*-effect in different systems, and the results of some measurements of the dissociation constants of *o*-substituted benzoic acids and of the velocities of hydrolysis of their esters are considered in this, the first part. A detailed account of the experimental results follows in Parts II and III.

The first fact upon which we wish to lay emphasis is that the *ortho*-effect is by no means a general one, for it is not observed in all aromatic compounds where the substituents are suitably placed with respect to the reacting group. It appears to operate, in fact, only when the latter contains an atom which is known to be a powerful electron-donor, *e.g.*, COR, CO_2R, NR_2. This is illustrated by the relative effects of two bromine atoms in *o*-positions in benzoyl chloride and benzyl chloride severally; the velocities of hydrolysis of 2 : 6- and 3 : 5-dibromobenzoyl chlorides, referred to that of the unsubstituted compound as unity, are 0·0112 and 13·5, while the figures for the corresponding benzyl chlorides are 0·12 and 0·07 (Olivier, *Rec. trav. chim.*, 1929, **48**, 227). The *ortho*-effect is never detectable, indeed, in the reactions of benzyl chlorides (cf. *idem, ibid.*, 1930, **49**, 697; Bennett and Jones, J., 1935, 1815). Again, Branch, Yabroff, and Bettmann (*J. Amer. Chem. Soc.*, 1934, **56**, 937, 1865) find no increase in strength in *o*-substituted phenylboric acids, $C_6H_4X{\cdot}B(OH)_2$, as compared with their isomerides. The characters of *o*-substituted phenols and their derivatives, moreover, do not indicate an effect of any magnitude; they are not more strongly acidic than the isomeric *m*- and *p*-substituted compounds, nor are they appreciably less reactive (*e.g.*, Boyd *et al.*, J., 1914, **105**, 2117; 1919, **115**, 1239; Burkhardt *et al.*, J., 1936, 17; the influences recorded by Davis, *loc. cit.*, in the reactions of alcohols with 1-substituted β-naphthols are probably inductive effects), and it may be noted in this connection that hydroxyl is predominantly an electron-accepting group.

Secondly, even among reactions of *o*-substituted carboxylic acids and their derivatives, there are instances where no unusual feature is observed. The data for the speeds of hydrolysis and alcoholysis of benzoyl chlorides with one *o*-substituent are rather conflicting (Berger and Olivier, *Rec. trav. chim.*, 1927, **46**, 516; Norris *et al.*, *J. Amer. Chem. Soc.*, 1935, **57**, 1415); these reactions are of a complicated character, and the effects of substituents in any position are difficult to interpret (Ingold, *Ann. Reports*, 1927, **24**, 157). Two notable examples of the definite absence of the *ortho*-effect are found, however,

in the reactions of *o*-substituted benzoic acids with di-*p*-tolyldiazomethane (Norris and Strain, *J. Amer. Chem. Soc.*, 1935, **57**, 187) and of the corresponding methyl esters with trimethylamine (Hammett and Pfluger, *ibid.*, 1933, **55**, 4079) :

$$R{\cdot}CO_2H + N_2C(C_6H_4{\cdot}CH_3)_2 \longrightarrow N_2 + R{\cdot}CO_2CH(C_6H_4{\cdot}CH_3)_2$$

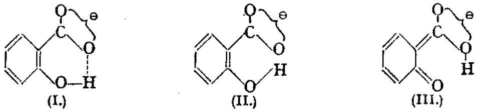
$$R{\cdot}CO_2CH_3 + N(CH_3)_3 \longrightarrow R{\cdot}CO_2^{\ominus} + N(CH_3)_4^{\oplus}$$

Yet, as pointed out above, the ionic equilibria and esterification reactions of these acids and the alkaline hydrolyses of the esters show marked *ortho*-effects. The value of the dissociation constant of *s*-trimethylbenzoic acid ($10^5K = 3{\cdot}75$, as compared with 6·6 for benzoic acid) leads to the conclusion that the *o*-methyl groups are exerting only their normal inductive effects, and the same is true of trimethylacetic acid ($10^5K = 0{\cdot}98$; cf. 1·8 for acetic acid) where also an " *ortho*-effect " might be expected. Nevertheless, when these acids are esterified, the energies of activation are very high in comparison with those for benzoic and acetic acids respectively (Hinshelwood and Legard, J., 1935, 587, 1588); the operation of an " *ortho*-effect " is thus indicated in the acid-catalysed reactions, although not in the strengths of the acids themselves.

Thirdly, our investigation of the alkaline hydrolysis of *o*-substituted benzoic esters (Part III) has shown that the relatively low speeds are to be ascribed to a decrease of approximately a power of 10 in the probability factor P of the kinetic equation $k = PZe^{-E/RT}$; the energies of activation are actually slightly less (appreciably less in ethyl *o*-chlorobenzoate) than those for the isomeric *m*- and *p*-substituted esters. Newling and Hinshelwood (J., 1936, 1357) have obtained similar results for the alkaline hydrolysis of ethyl *iso*butyrate. On the other hand, an " *ortho*-effect " in acid-catalysed esterification involves an *increase* in E, and usually an *increase* in P also (Hinshelwood and Legard, *loc. cit.*).

In seeking a solution of the problems presented by the above observations, we are fully aware that steric hindrance of the Victor Meyer type cannot be neglected as a possible cause of the peculiarities shown by *o*-substituted compounds. It may, for example, be entirely or almost entirely responsible for the relatively high dissociation constants of *o*-phenyl- and *o*-phenoxy-benzoic acids (see Part II), and it may also be a contributory factor in many other instances. We believe, nevertheless, that the *ortho*-effect frequently originates, to a great extent, in chelation processes similar to those which produce abnormalities in the physical properties of certain *o*-substituted phenols (Sidgwick and Callow, J., 1924, **125**, 527). At the same time, we do not suggest that this is ever the *sole* cause of the effect, or that other factors should be excluded.

The relatively high dissociation constant of salicylic acid ($10^5K = 105$) cannot be due entirely to steric hindrance by so small a group as hydroxyl, particularly in view of the fact that methoxyl does not lead to any striking increase in the constant, and Branch and Yabroff (*J. Amer. Chem. Soc.*, 1934, **56**, 2568) have postulated the formation of a hydrogen bond between the hydroxyl and carboxyl groups. The positions of the atoms in salicylic acid are peculiarly favourable to hydrogen-bond formation (see Sidgwick and Callow, *loc. cit.*; Sidgwick, " The Electronic Theory of Valency," Oxford University Press, 1927,

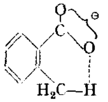


(I.) (II.) (III.)

Ch. XIV), and the resonance to which the bond is due is facilitated by electronic rearrangements [see (II) and (III)]. It is to be anticipated that negatively-charged carboxyl (carboxylate ion) will form such a bond more readily than the undissociated group, and the high acidity may therefore arise almost entirely from the occurrence in the *ion* of the process represented in (I) [the unperturbed structures are (II) and (III)]. This will decrease the electron-availability of the $-CO_2^{\ominus}$ group, and will thus militate against reassociation. Baker has suggested (*Nature*, 1936, **137**, 236) that the further large increase in strength in

2 : 6-dihydroxybenzoic acid ($K = 5 \times 10^{-2}$) is due to the formation of hydrogen bonds by *both* oxygens of carboxyl.

It is probable that an alkyl group can form a hydrogen bond, provided that an electron-donating atom is suitably placed with respect to it, and that the resonance (which involves what is virtually an ionisation process) is made possible by a neighbouring electron-attractive group (*e.g.*, in *o*-nitrotoluene, Sidgwick and Callow, *loc. cit.*; cf. also Evans, J., 1936, 785). The fact that *o*-toluic acid ($10^5K = 12{\cdot}35$) is appreciably stronger that its *m*- and *p*-isomerides (and than benzoic acid itself) may therefore be attributed to the formation, to a limited extent, of a hydrogen bond as in (IV). Comparison of the strengths of salicylic and *o*-toluic acids shows that in the latter the average state must approach the unperturbed structure (V) far more closely than (VI). The same interpretation is not applicable to *o*-*tert*.-butylbenzoic acid, which is markedly stronger than *o*-toluic acid ($10^5K = 35$; Shoesmith and Mackie, J., 1936, 300), although hydrogen-bond formation is not possible. Other effects must operate here.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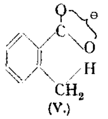
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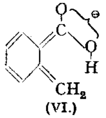
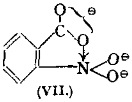
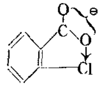

(VI.)

In *o*-nitro- and the *o*-halogeno-benzoic acids (excluding *o*-F), an oxygen of the carboxyl group may act as electron donor in the formation of a co-ordinate bond of the normal type. Chlorine, bromine, and iodine can expand their valency groups beyond eight electrons (the rather high value of K for *o*-fluorobenzoic acid must be accounted for otherwise), and Bennett and Willis (J., 1929, 256), in their formulation of the additive products of nitro-compounds with amines and hydrocarbons, ascribe electron-acceptor properties to the nitrogen atom of the nitro-group. Structures (VII) and (VIII) are therefore suggested for the ions of *o*-nitro- and *o*-chloro-benzoic acids; a five-membered ring is postulated here (cf. examples in the papers by Sidgwick and Callow and by Evans, already referred to). In the *o*-substituted phenylacetic and cinnamic acids, and in *o*-methoxybenzoic acid, the positions of the atoms are unsuitable for chelation, and there is no great increase in the dissociation constant.


(VII.)


(VIII.)

If the *ortho*-effect has its origin very largely in phenomena of this kind, the necessity that the reacting group should be electron-donating is understood; the chelation processes suggested above could not occur, for example, in *o*-substituted benzyl chlorides, and hydrogen-bond formation in a phenol (OH acting as acceptor, OH ←—, compare Sidgwick and Callow, *loc. cit.*) would not be expected to have much influence upon its dissociation or upon the electron-availability of the oxygen.

The second point which has been emphasised, *viz.*, the absence of an *ortho*-effect in certain processes involving *o*-substituted acids and esters, has next to be considered. It has already been pointed out that, on our view, the high dissociation constants of acids are due principally to decreased facility of the reassociation, since chelation will occur most extensively in the ion. In reactions such as those formulated on p. 1423, the un-ionised acid (or ester), and not the anion, is the reacting entity, and it is therefore not surprising that the *ortho*-effect becomes small or negligible. In *s*-trimethylbenzoic and trimethylacetic acids, where the dissociation constants do not indicate an *ortho*-effect, it must be supposed that some factor inhibits the formation of the hydrogen bond, and it is not possible at present

to determine whether the inductive effects of the additional methyl groups are to any extent responsible for this.

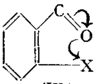
Chelation in the anion of the acid does not account for *ortho*-effects in esterification processes, or in the hydrolysis of esters. In accordance with a previous suggestion (Evans, Morgan, and Watson, J., 1935, 1171), we represent these processes as follows:

$$R{\cdot}CO_2H + H^+ \rightleftarrows R{\cdot}\overset{+}{C}\begin{smallmatrix}\diagup OH\\ \diagdown OH\end{smallmatrix} \xrightarrow{R'OH} R{\cdot}C\begin{smallmatrix}\diagup OH\\ -OH\\ \diagdown OR'H\end{smallmatrix} \longrightarrow R{\cdot}CO_2R' + H_2O + H^+$$

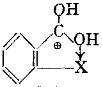
$$R{\cdot}CO_2R' + OH^- \rightleftarrows R{\cdot}C\begin{smallmatrix}\diagup \bar{O}\\ -OH\\ \diagdown OR'\end{smallmatrix} \longrightarrow R{\cdot}CO_2^- + R'OH$$

The carboxyl and carbethoxyl groups have resonance energies of about 1·2 v.e. (Pauling and Sherman, *J. Chem. Physics*, 1933, 1, 606), and in the complex formed on collision with the catalyst the resonance is destroyed. The electrons are now in higher energy levels and consequently more reactive. If, therefore, other atoms are suitably placed, chelation or hydrogen-bond formation is likely to occur *simultaneously* with the attack of the catalyst as represented in (IX). For acid-catalysed esterification the resulting decrease in electron-availability of the oxygen will lead to a high energy of activation (compare the prototropy of propiophenone; Evans, *loc. cit.*), but in alkaline hydrolysis (where the catalyst is added at carbon and not at oxygen) there will be no such effect; the slightly low value of E may be due to the facilitation of the electromeric change C=O.

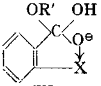
If the complex is highly chelated, its constitution will be as represented in (X) (for esterification) or (XI) (for hydrolysis). The effect of the chelation is a drift of electrons away from carbon, and in esterification the subsequent change, *viz.*, addition of R'OH,



(IX.)



(X.)



(XI.)

will thereby be facilitated, whereas in hydrolysis, which requires the elimination of $^-$OR', the process will be rendered more difficult. This explains the effect of *o*-substituents upon the P factor if, as suggested in Part III, this factor is governed largely by the second stage of the complete change.

Finally, the behaviour of ethyl *o*-fluorobenzoate on alkaline hydrolysis is in complete harmony with an interpretation of this type. The values of E and P are here almost the same as those found for the isomeric *p*-substituted ester. The formation of a co-ordinate bond is impossible, since fluorine cannot increase its valency group, and this enforced absence of chelation is accompanied by the complete non-existence of all the criteria of the *ortho*-effect.

A satisfactory interpretation of a number of phenomena is thus found along the lines indicated. Nevertheless, other important factors may also be involved, and in no case is the absence of these assumed. The study of the *ortho*-effect is being continued in these laboratories.

The Technical College, Cardiff. [*Received, June 22nd*, 1937.]

293. *Studies of the* ortho-*Effect. Part II. The Dissociation Constants of Some* o-*Substituted Acids.*

By J. F. J. Dippy and R. H. Lewis.

The data here recorded extend our knowledge of the strengths of substituted aromatic acids. Special reference is made to the *o*-acids; in the benzoic series most of these are considerably stronger than their isomerides but this does not apply to the phenylacetic and cinnamic acids, as far as we have determined. Notable enhancement of acid strength occurs in other structures which admit of steric influences.

The greater bulk of phenyl as compared with methyl may be largely responsible for the striking increase in strength in passing from *o*-methoxy- to *o*-phenoxy-benzoic acid.

The somewhat low constant for *o*-nitrophenylacetic acid is attributed to a "hydrogen bond" between nitroxyl and methylene.

Values of the thermodynamic dissociation constants of several *o*-substituted benzoic acids in water at 25° have already been recorded and these are now supplemented by others listed below. *m*- and *p*-Phenoxybenzoic acids are included, since these have not previously been measured. Table I consists of the mean mobility data and the values of both classical and thermodynamic constants, together with the determinations ($10^5 K_{class.}$) which have already appeared in the literature.

Table I.

Acid.	Λ_0 (Na salt).	Λ_0 (acid).	$10^5 K_{class.}$	$10^5 K_{therm.}$	Earlier values.
o-Toluic	81·2; 81·9	381·2	$12{\cdot}7_5$	$12{\cdot}3_5$	12·0[1]; 12·5[2] 13·0[3]; 13·5[4]
o-Phenylbenzoic	73·6	373·2	35·5	34·7	—
o-Methoxybenzoic	80·3; 80·6	380·0	8·29	8·06	8·2[1]
o-Phenoxybenzoic	73·4	373·0	30·1	29·7	—
m-Phenoxybenzoic	73·7	373·3	11·3	11·2	—
p-Phenoxybenzoic	74·9	374·5	3·03	3·00	—
o-Nitrobenzoic	78·9; 78·9	378·5	660	671	616[1]; 650[3] 620[5]
o-Nitrophenylacetic	79·0; 79·0	378·6	$10{\cdot}1_5$	9·90	—
o-Chlorocinnamic	78·2	377·8	5·88	5·83	3·9[6]
p-Chlorocinnamic	78·5	378·1	3·89	3·86	—

[1] Ostwald, *Z. physikal. Chem.*, 1889, **3**, 415. [2] Euler, *ibid.*, 1896, **21**, 265. [3] Schaller, *ibid.*, 1898, **25**, 517. [4] White and Jones, *Amer. Chem. J.*, 1910, **44**, 184. [5] Kendall, J., 1912, **101**, 1295. [6] Betti and Lucchi, *Atti R. Accad. Lincei*, 1935, **22**, 367.

The older constants for *o*-toluic and *o*-methoxy- and *o*-nitro-benzoic acids approximate to our values, but that recently accorded to *o*-chlorocinnamic acid by Betti and Lucchi is much lower than ours, and scarcely different from that of the unsubstituted acid. It is possible that the sparing solubility of this acid in water added to the difficulties of these workers. There also exists complete lack of agreement between our data (already published) for *o*-chloro- and *o*-bromo-phenylacetic acids and those of Betti and Manzoni (*Atti R. Accad. Lincei*, 1935, **22**, 284), who record classical constants of 13·5 and 19·2 respectively, whereas we found 8·82 and 9·09.

We have already pointed out (J., 1936, 645) that at higher dilutions the classical constants calculated for *o*-iodobenzoic acid are slightly lower than the corresponding thermodynamic constants, and the reason has also been indicated. A similar and much more marked deviation exists in the results published here for the stronger *o*-nitrobenzoic acid at all the concentrations employed (see Table III).

Examination of the Λ_0 data for isomeric acids in the benzoic series shows that the anion mobility tends to be greatest when the substituent occupies the *o*-position; this is the case, however, only where the smaller groups are concerned.

Table II records the relative strengths of substituted benzoic and phenylacetic acids based on the data ($K_{therm.}$) published here and those already recorded by Dippy and Williams

(J., 1934, 161, 1888; 1935, 343) and Dippy and Lewis (J., 1936, 644); in each series the parent unsubstituted acid is taken as unity.

TABLE II.

	Benzoic series.			*Phenylacetic series.*		
	o-.	*m*-.	*p*-.	*o*-.	*m*-.	*p*-.
Me	1·97	0·867	0·676	—	—	0·875
HO *	15·9	1·26	0·440	—	—	—
MeO	1·29	1·30	0·538	—	—	0·893
PhO	4·74	1·79	0·478	—	—	—
F	8·63	2·18	1·15	—	—	1·16
Cl	18·2	2·36	1·68	1·76	1·48	1·32
Br	22·3	2·46	1·71	1·81	—	1·33
I	21·9	2·25	—	1·88	1·42	1·36
NO_2	107	5·19	6·00	2·03	2·21	2·89

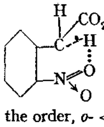
* These figures are derived from the measurements ($K_{therm.}$) of Branch and Yabroff (*J. Amer. Chem. Soc.*, 1934, 56, 2568).

Almost all *o*-substituted benzoic acids are markedly stronger than the *m*- and *p*-isomerides, and a variety of causes may be responsible for this. The increase in strength in passing from *o*-methoxy- to *o*-phenoxy-benzoic acid can reasonably be attributed to the great difference in bulk of the substituents; the polar effects of these groups should not be very dissimilar (note also that the strengths of *o*-phenoxy- and *o*-phenyl-benzoic acids are alike). Elsewhere, methoxyl and phenoxyl behave in comparable manner; in the *p*-position they reduce the strength of benzoic acid whilst in the *m*-position they enhance it. The well-known combination of inductive ($- I$) and electromeric effects ($+ T$) in alkoxyl accounts for this (cf. J., 1935, 346). It is interesting, however, that in the *p*-position phenoxyl reduces K more effectively than does methoxyl, whereas in the *m*-position it leads to a comparatively greater strength. This last observation doubtless arises from the inherent electron-attractive character of phenyl (cf. Dippy and Lewis, this vol., p. 1008) as opposed to the electron-repulsive nature of methyl. On the other hand, in the *p*-phenoxyl group the ambipolar tautomeric character of phenyl, now free to exhibit itself, apparently gives rise to a greater accession of electrons towards the nucleus than does the inductive effect of methyl.

The order of strengths of anisidines and phenetidines, *viz.*, *o*- and *m*- < H < *p*- (Hall and Sprinkle, *J. Amer. Chem. Soc.*, 1932, 54, 3469), is wholly consistent with the observations on alkoxybenzoic acids.

It is noticeable that in the phenylacetic acids *o*-substituents fail to produce abnormally large strengths (see Table II); actually, in the halogeno-compounds, for instance, there is a very *gradual* fall *o*- > *m*- > *p*- (cf. chlorocinnamic acids). It is remarkable how very similar the relative effects of the halogens are in each position in both series, and also that there is a much greater relative diminution in the strengths of *m*-acids than of *p*-acids in passing from the benzoic to the phenylacetic series.

In the nitro-acids the order is *p*- > *m*- > *o*-; it is surprising that *o*-nitrophenylacetic acid is not comparable with the *p*-acid in being rather stronger than the *m*-acid, since electromeric disturbances should operate from the *o*- and *p*-positions in such a way as to facilitate ionisation. The reason, however, may be that nitroxyl in the *o*-acid is capable of chelating with hydrogen of the methylene contained in the side-chain (see inset; cf. Sidgwick and Callow, J., 1924, 125, 538, regarding *o*-nitrotoluene). This chelation is probably not extensive, but considerable enough to reduce acid strength to give the order, *o*- < *m*-.



It has already been pointed out (Flürscheim, *Chem. and Ind.*, 1925, 44, 249; cf. Hey, J., 1928, 2321; Dippy and Lewis, this vol., p. 1012) that the increase in strength in going from the *trans*- to the *cis*-forms in such acids as crotonic and cinnamic may be correlated with the abnormality noted in the *o*-substituted benzoic acids, on the grounds of proximity of groups. The fact that α-naphthoic acid ($10^5K = 20·4$) is stronger than the β-acid ($10^5K = 6·78$) (Bethmann, *Z. physikal. Chem.*, 1890, 5, 399) can be considered to have a similar bearing. It is noteworthy that German, Jeffery, and Vogel (J., 1935, 1624) found

the primary dissociation constant of *cyclo*propane-1 : 1-dicarboxylic acid to be very much greater ($10^4K = 150{\cdot}0$) than those of the homologous acids containing four-, five-, and six-membered rings ($10^4K = 7{\cdot}47$, 5·89, and 3·54 respectively); it was indicated that the distances (r) separating the carboxyl groups in the last three acids were comparable, and much greater than r in the stronger acid. This observation may be regarded simply as another case of abnormality in acid strength due to close proximity of groups.

There is no ponderable *ortho*-effect in phenols, and in the following data such an effect is totally absent,

Substituent.		*o*-.	*m*-.	*p*-.	(H = *ca.* $1{\cdot}0 \times 10^{-10}$.)
CH_3	($10^{11}K$)	6·3	9·8	6·7	(Boyd, *J.*, 1915, **107**, 1540).
NO_2	($10^{8}K$)	6·8	1·0	6·5	(Holleman and Herwig, *Rec. trav. chim.*, 1902, **21**, 444).

It is also remarked in Part I that the introduction of *any* *o*-substituent into aniline *depresses* the strength abnormally; the following instances serve to illustrate this clearly :

Substituent.		*o*-.	*m*-.	*p*-.	(H = *ca.* 5×10^{-10}.)
CH_3	($10^{10}K$)	0·73	2·9	11·3	(Farmer and Warth, *J.*, 1904, **85**, 1726; Hall and Sprinkle, *loc. cit.*).
NO_2	($10^{12}K$)	0·015	4·2	1·1	(Löwenherz, *Z. physikal. Chem.*, 1898, **25**, 405).

On rudimentary grounds it is to be expected that both *o*- and *p*-toluidine will be stronger than *m*-toluidine, and also that *o*-nitroaniline will be only slightly weaker than *m*-nitroaniline and comparable to the *p*-isomeride

A lower K ($\times 10^{-11}$) for α-naphthylamine (9·9) than for β-naphthylamine (20) (Farmer and Warth, *loc. cit.*) is in harmony with the strengths of *o*-substituted anilines. A steric influence may also be traced in aliphatic amines; Harned and Owen (*J. Amer. Chem. Soc.*, 1930, **52**, 5079) show that progressive methylation of ammonia does not lead to a steady increase in basic strength, as would be anticipated from the operation of the simple inductive effect of alkyl (10^5K: NH_3, 1·79; NH_2Me, 43·8; $NHMe_2$, 52·0; NMe_3, 5·45). Bredig (*Z. physikal. Chem.*, 1894, **13**, 298) and, more recently, Hall and Sprinkle (*loc. cit.*) have observed, with higher alkyl groups, a similar diminution in strength in passing from secondary to tertiary bases.

Experimental.

Details of the conductivity measurements have been described elsewhere (Dippy and Williams; Dippy and Lewis, *locc. cit.*). The water, as usual, had a conductivity of 0·9—1·0 gemmho, and the stock solutions of acids were made up to 250 ml. except in the cases of the less soluble *o*-phenylbenzoic (500 ml.), and *o*-, *m*-, and *p*-phenoxybenzoic, and *o*- and *p*-chlorocinnamic acids (1 l.).

Materials.—*o*-Methoxybenzoic acid was obtained from the corresponding benzaldehyde by oxidation with alkaline permanganate. *o*-Toluic acid was supplied by British Drug Houses, Limited, and *o*-nitrobenzoic and *o*-nitrophenylacetic acids by Schering–Kahlbaum. The specimens of *o*-phenyl- and *o*-, *m*-, and *p*-phenoxy-benzoic acids were kindly provided by Dr. G. Lock, and *o*- and *p*-chlorocinnamic acids by Professor F. Böck. In each case preliminary purification was effected with a suitable solvent until the m. p. could be improved no further; successive recrystallisations from conductivity water then followed. The m. p.'s of the pure dry acids are recorded below, together with the highest m. p. in the literature. Satisfactory equivalents were obtained throughout.

Acid.	M. p. (corr.).	M. p. (literature).	
o-Toluic	107·5°	107—108°	(Ciamician and Silber, *Ber.*, 1912, **45**, 41).
o-Phenylbenzoic	114	113—114	(Weger and Döring, *Ber.*, 1903, **36**, 880).
o-Methoxybenzoic	101·5	100—101	(Claisen, *Annalen*, 1919, **418**, 87).
o-Phenoxybenzoic	113	113	(Graebe, *Ber.*, 1888, **21**, 503).
m-Phenoxybenzoic	146·5	145	(Griess, *ibid.*, p. 980).
p-Phenoxybenzoic	161·5	159·5	(Griess, *loc. cit.*).
o-Nitrobenzoic	148	148	(Holleman, *Rec. trav. chim.*, 1898, **17**, 248; Flaschner and Rankin, *Monatsh.*, 1910, **31**, 38).
o-Nitrophenylacetic	141	141	(Salkowski, *Ber.*, 1884, **17**, 507).
o-Chlorocinnamic	209·5	211	(Lasch, *Monatsh.*, 1913, **34**, 1654).
p-Chlorocinnamic	249	240—242	(Gabriel and Hertzberg, *Ber.*, 1883, **16**, 2036).

Both chlorocinnamic acids were *trans*-modifications.

The measurements made on the ten acids are summarised in Table III. In each instance details of one complete run are given.

TABLE III.

Cell const.	10^3C.	Λ.	$10^5K_{class.}$	$10^5K_{therm.}$	Cell const.	10^3C.	Λ.	$10^5K_{class.}$	$10^5K_{therm.}$
				o-*Toluic acid.*					
0·1363	3·086	70·62	(13·00)	12·5$_5$	0·07319	0·9917	114·3	12·7$_5$	12·4$_5$
	1·477	96·27	12·6	12·2$_5$		0·5202	147·6	12·7$_5$	12·5
	1·282	102·4	12·6$_5$	12·3$_5$					
		14 Determinations : limits of $10^5K_{therm.}$, 12·2—12·5$_5$.							
				o-*Phenylbenzoic acid.*					
0·07906	0·4453	215·4	35·1	34·5	0·07906	0·1070	299·3	35·4	34·6
	0·2652	246·3	(33·9$_5$)	(33·5)		0·07789	313·7	34·5	34·4
	0·1474	283·5	35·9$_5$	35·2					
		4 Determinations : limits of $10^5K_{therm.}$, 34·4—35·2.							
				o-*Methoxybenzoic acid.*					
0·1360	4·501	48·26	8·31	8·00	0·07285	0·9099	98·31	8·22	8·03
	2·107	67·95	8·20	(7·96)		0·7498	106·9	8·26	8·07
	1·880	71·69	8·24	8·01		0·7487	107·2	8·23	8·05
		12 Determinations : limits of $10^5K_{therm.}$, 8·00—8·12.							
				o-*Phenoxybenzoic acid.*					
0·07906	0·5358	194·5	30·4$_5$	29·6$_5$	0·05421	0·1491	273·3	29·9$_5$	29·8
	0·4468	205·3	30·1	29·4$_5$		0·07698	307·5	29·8	29·7
	0·2063	254·7	30·3$_5$	29·9$_5$					
		5 Determinations : limits of $10^5K_{therm.}$, 29·4$_5$—29·9$_5$.							
				m-*Phenoxybenzoic acid.*					
0·07906	0·1911	196·6	11·2	11·1	0·05421	0·1501	213·7	11·5	11·4
	0·1907	196·9	11·2$_5$	11·1		0·1349	219·5	11·3	11·2$_5$
	0·1858	199·3	11·3$_5$	11·2$_5$					
		10 Determinations : limits of $10^5K_{therm.}$, 11·1—11·4.							
				p-*Phenoxybenzoic acid.*					
0·07906	0·1552	132·2	2·99$_5$	2·96	0·05421	0·09736	159·6	3·08	3·05
	0·1206	146·3	3·02	2·99		0·08079	170·0	3·05	3·03
						0·06637	180·7	2·98$_5$	2·97
		12 Determinations : limits of $10^5K_{therm.}$, 2·94—3·05.							
				o-*Nitrobenzoic acid.*					
0·1361	2·119	301·4	660	665	0·1361	1·623	314·4	661	670
	1·849	308·4	661	668		1·462	319·2	663	679
	1·776	310·0	658	667		1·129	329·6	663	(682)
		12 Determinations : limits of $10^5K_{therm.}$, 665—679.							
				o-*Nitrophenylacetic acid.*					
0·1361	4·230	54·23	10·1$_5$	9·77	0·07285	1·128	98·28	10·2$_5$	10·0
	2·050	75·39	10·1$_5$	9·87		0·7387	117·1	10·2$_5$	10·0$_5$
	1·661	83·20	10·3	10·0		0·5988	127·7	10·2$_5$	10·0$_5$
		12 Determinations : limits of $10^5K_{therm.}$, 9·71—10·0$_5$.							
				o-*Chlorocinnamic acid.*					
0·07291	0·1113	193·0	5·93	5·87	0·07291	0·08828	209·4	6·09	(6·04)
	0·09767	203·2	6·11	(6·06)	0·05142	0·08034	213·6	5·92	5·87
	0·09342	204·4	5·96	5·91		0·07145	221·6	5·95	5·90
		13 Determinations : limits of $10^5K_{therm.}$, 5·69—5·91.							
				p-*Chlorocinnamic acid.*					
0·07291	0·07068	193·9	3·82	3·79	0·07291	0·06295	203·2	3·92$_5$	3·90
	0·06630	199·1	3·88$_5$	3·85$_5$	0·05142	0·05631	207·9	3·78$_5$	3·76
		17 Determinations : limits of $10^5K_{therm.}$, 3·76—3·94.							

We are grateful to Professor F. Böck and Dr. Gunther Lock, both of Vienna, for their gifts of acids, and to Imperial Chemical Industries, Limited, for grants to this Department.

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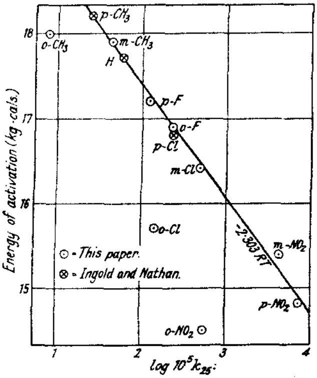
294. *Studies of the* ortho-*Effect. Part III. Alkaline Hydrolysis of Benzoic Esters.*

By D. P. Evans, J. J. Gordon, and H. B. Watson.

It has been found by Ingold and Nathan (J., 1936, 222) that the effect of a *p*-substituent upon the alkaline hydrolysis of ethyl benzoate is to change the energy of activation, the *P* factor of the kinetic equation not being influenced to any extent. The results described below show that the same remark applies to *m*-substituents, but that a group in the *o*-position leads to a relatively low velocity of hydrolysis by decreasing the *P* factor. The suggestion is made that this is due to a reduction in the facility with which the activated complex (formed by the ester and hydroxyl ion as the first step in the complete change) breaks down to give the products.

It has now become evident that the mere comparison of velocity coefficients determined at a single temperature may throw but little light upon the influences governing reactivity, and may in some cases, indeed, lead to incorrect conclusions. In order to extract the information which a study of reaction speeds is capable of yielding, the velocity coefficient must be analysed into its component parts. Hinshelwood (this vol., p. 635; compare Hinshelwood and Winkler, J., 1936, 371) has given ample justification for the treatment of reaction velocity problems on the basis of the collision theory, and for the use of the equation $k = PZe^{-E/RT}$, where E is the energy of activation and P represents the proportion of the sufficiently energised collisions which actually lead to the formation of the reaction products. The collision method is "not really at a fundamental disadvantage" as compared with the thermodynamic treatment of Polanyi and others, and it has the advantage of providing a simple physical picture of the reaction. It attributes changes in velocity to variations in E, in P, or in both (Z does not change seriously from an average value of about $2{\cdot}8 \times 10^{11}$), and the determination of these two quantities for a series of reactions may be regarded as a satisfactory method of attacking problems such as those relating to the influence of substituent groups upon reactivity.



In at least three instances, *viz.*, the chlorination of phenolic ethers (Bradfield *et al.*, *Chem. and Ind.*, 1932, **51**, 254, and references there cited), the benzoylation of anilines (Williams and Hinshelwood, J., 1934, 1079), and the alkaline hydrolysis of ethyl benzoates (Ingold and Nathan, *J.*, *1936*, *222*), *it has been shown that the differences in velocity* accompanying constitutional changes are to be ascribed, almost entirely at least, to variations in the energy of activation, *P* being altered but little. Ingold and Nathan point out that, in these reactions where substituents influence the energy of activation almost exclusively, "induced polar effects may be assumed to be isolated from local disturbances." Such is the case, for example, in the reaction which they studied, *viz.*, the alkaline hydrolysis of *p*-substituted ethyl benzoates. The same applies to the corresponding *m*-substituted esters, and we have now shown that, here again, the value of *P* is almost constant. Such constancy is indicated most clearly by a linear plot of *E* against log *k*, the straight line having a slope of $-2{\cdot}303RT$; this theoretical line is shown in the figure, and it will be seen that the points relating to the *m*-substituted ethyl benzoates, as well as those for the isomeric *p*-substituted esters, approximate to it very closely.

When the substituent is in the *o*-position, however, a different state of affairs arises. The *o*-substituted esters are hydrolysed, as a rule, much more slowly than their *m*- and *p*-isomerides, as has been shown by Kindler (*Annalen*, 1928, **464**, 278) and others. We have determined the rates and energies of activation of the alkaline hydrolysis of a number of these esters, and the points relating to them are included in the figure. Our results are summarised below.

Alkaline Hydrolysis of Benzoic Esters, $X{\cdot}C_6H_4{\cdot}CO_2Et$, *in* 85% *Alcohol.*

X.	10^3k_{50}.	10^3k_{35}.	10^3k_{25}.	10^2P.	E (cals.).	X.	10^3k_{50}.	10^3k_{35}.	10^3k_{25}.	10^2P.	E (cals.).
H	6·28	1·68	0·621	2·17	17,700	*m*-CH_3	4·57	1·18	0·433	2·13	17,900
o-CH_3	0·809	0·207	0·0776	0·45	18,000	*m*-Cl	39·6	11·8	4·77	1·82	16,400
o-F	21·0	5·81	2·32	2·13	16,900	*m*-NO_2	—	100	42·9	3·08	15,400
o-Cl	11·0	3·38	1·39	0·17	15,700	*p*-F	12·0	3·20	1·26	1·92	17,200
o-NO_2	38·8	12·75	5·41	0·08	14,500	*p*-NO_2	—	162	72·0	1·86	14,800

(In the above table, k is the bimolecular velocity coefficient expressed in l./g.-mol.-sec., and P is calculated from the kinetic equation on the assumption that $Z = 2{\cdot}8 \times 10^{11}$.)

Three interesting facts emerge from our study of the alkaline hydrolysis of *o*-substituted benzoic esters :

1. The hydrolysis of ethyl *o*-fluorobenzoate does not reveal the operation of any factors which are not observed in the *m*- and the *p*-substituted ester; in the plot of E against log k, this ester gives a point lying on the theoretical line.

2. For the remaining *o*-substituted esters, the values of E are not very different from those obtained for their *m*- and *p*-isomerides. On the whole, they show a tendency to be slightly *lower*, that for ethyl *o*-chlorobenzoate definitely so.

3. The *o*-esters, except the *o*-fluoro-ester, give values of P which are *smaller* by about a power of 10 than those found for the others. The lower velocity observed when a substituent is introduced into the *o*-position is therefore to be attributed to a decrease in the proportion of energised collisions which actually lead to the reaction products.

Hinshelwood and Winkler (*loc. cit.*) have directed attention to several causes which might reduce the value of the P factor for reactions in solution. It has long been recognised that when two molecules collide with the necessary energy, the formation of the transition complex may still require the fulfilment of definite phase and orientation conditions. But even when all these demands are satisfied, and the molecules have actually "got to grips," the consummation of the reaction is yet dependent upon the existence of the right conditions for the breakdown of the complex to give the products. Hinshelwood has suggested, for example (*Trans. Faraday Soc.*, **1936**, **32**, 970), that it may be necessary for solvent molecules to be suitably placed for the removal of energy from the complex. We believe that, in catalysed reactions, P may depend very largely upon the fulfilment or otherwise of the conditions necessary for the transformation of the complex into the actual products, *i.e.*, for the completion of the second stage in a scheme such as the following: $\text{A} + \text{Catalyst} \longrightarrow [\text{A, Catalyst}] \xrightarrow{\text{B}} \text{Products} + \text{Catalyst}$. The alkaline hydrolysis of an ester may be formulated

$$R{\cdot}CO_2R' + OH^- \longrightarrow R{\cdot}C\begin{cases} O^- \\ OH \\ OR' \end{cases} \longrightarrow R{\cdot}CO{\cdot}O^- + R'OH$$

and the velocity depends, *inter alia*, upon the probability that the complex will break down to give anion and alcohol; the possible intervention of a solvent molecule at this stage, as suggested by Newling and Hinshelwood (J., **1936**, **1357**), does not influence the argument.

The relatively small values of P observed in the alkaline hydrolysis of *o*-substituted ethyl benzoates *might* be due to a decrease in the proportion of fruitful collisions between ester and hydroxyl ion, but since, in acid-catalysed esterification, *o*-substituents actually cause an increase in P (Hinshelwood and Legard, J., **1935**, 592), we do not regard this as probable. In a mechanism of esterification suggested by Evans, Morgan, and Watson (J., **1935**, **1171**), the acid, after activation by the catalyst, co-ordinates with a molecule of alcohol, whereas in alkaline hydrolysis the complex releases an —OR group (see scheme

above; cf. Polanyi and Szabo, *Trans. Faraday Soc.*, 1934, **30**, 508); we suggest, therefore, that the "*ortho*-effect" observed in these hydrolyses arises from the operation of some factor which reduces the facility with which the products are formed from the complex, but also assists the co-ordination with a molecule of alcohol (in esterification processes). The possible nature of this factor is considered in Part I.

EXPERIMENTAL.

Materials.—The ethyl benzoate after fractionation had b. p. 103°/20 mm. The three ethyl nitrobenzoates were purchased, and purified by recrystallisation to constant m. p.; m. p.'s, *o*-NO_2, 30·5°; *m*-NO_2, 42°; *p*-NO_2, 57°. The ethyl *o*- and *m*-toluates and -chlorobenzoates were prepared from the corresponding acids by the usual esterification process and fractionated at least three times; b. p.'s, *o*-CH_3, 110°/17 mm.; *m*-CH_3, 110°/20 mm.; *o*-Cl, 130°/20 mm.; *m*-Cl, 121°/20 mm. Ethyl *p*-fluorobenzoate was prepared from ethyl *p*-aminobenzoate as described by Schiemann and Winkelmüller ("Organic Syntheses," Vol. 13, p. 52), b. p. 105°/30 mm., m. p. 26° (cf Dippy and Williams, J., 1934, 1466). Ethyl *o*-fluorobenzoate was obtained by esterification of *o*-fluorobenzoic acid, also prepared by the Balz–Schiemann method, according to the details given by Dippy and Williams (*loc. cit.*), b. p. 105°/10 mm. All liquid esters were fractionated immediately before use, considerable head and tail fractions being neglected.

Velocity Measurements.—The aqueous-alcoholic medium employed was prepared as follows. Ethyl alcohol after being shaken with silver oxide was kept over freshly baked lime, from which it was subsequently distilled. This alcohol was suitably diluted with conductivity water; observed density of medium, $d_{4^\circ}^{20^\circ}$ 0·8314, corresponding to 84·8% of alcohol by weight. Errors due to possible non-reproducibility of the medium were avoided by preparing a large stock. The stock solution of alkaline hydrolysing agent consisted of *N*/5-sodium hydroxide ("Analar") in this medium. In the kinetic measurements the ester and sodium hydroxide were used in equivalent amounts, and the bimolecular velocity coefficients were calculated from the equation $k_2 = (1/t) \,.\, x/(a - x)a$. At the dilutions used (0·05*M*) this procedure was found to be more satisfactory than that of Ingold and Nathan (*loc. cit.*), who employed excess of ester.

The ester was weighed out accurately in a 100-ml. stoppered flask, and made up to 75 ml. with 84·8% alcohol, at the temperature of the bath. 25 Ml. of sodium hydroxide in 84·8% alcohol at the same temperature were added, and the flask well shaken. Zero time was taken at half delivery of the alkali. At suitable intervals, 10 ml. of reaction mixture were withdrawn, added to 10 ml. of cooled *N*/15-hydrochloric acid, and titrated with *N*/20-sodium hydroxide, bromothymol-blue being used as indicator. Each end-point was matched against a colour standard consisting of a freshly prepared solution of 15 ml. of *M*/30-sodium benzoate in 15 ml. of 50% aqueous alcohol containing the same amount of indicator as used in the titration. Except for the more rapid reactions of the nitrobenzoic esters, we estimate the accuracy of the velocity coefficients as ± 1·5%. The Arrhenius straight line was followed accurately in every case.

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295. *Studies on Hydrogen Cyanide. Part X. The Tetrapolymer.*

By L. E. HINKEL, G. O. RICHARDS, and O. THOMAS.

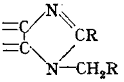
The previous evidence for the structure of the polymerised form of hydrogen cyanide is reviewed and further evidence is adduced for its quadrimolecular nature. The view that the polymer is diaminomaleic dinitrile is shown to be incorrect, and experiments now described indicate it to be aminoiminosuccinonitrile.

LANGE (*Ber.*, 1873, **6**, 99) obtained a white crystalline compound from the black solid resulting from the polymerisation of liquid hydrogen cyanide. Since this compound yielded aminoacetic acid on hydrolysis, he considered it to be a tripolymer having the structure of aminomalononitrile. This structure was supported by later workers (Wippermann, *Ber.*, 1874, **7**, 167; Lescoeur and Rigaut, *Compt. rend.*, 1879, **69**, 310; Bamberger and Rudolf, *Ber.*, 1902, **35**, 1682). In order to confirm the structure of the polymer,

Grischkevitsch-Trochimovski (*Rocz. Chem.*, 1921, **1**, 468; J., 1923, 1424) condensed it with benzaldehyde and claimed to have obtained a derivative of the type $R\cdot CH{:}N\cdot CH(CN)_2$, without, however, confirming this result by analysis. Bedel (*Compt. rend.*, 1923, **176**, 168) in attempting to determine the molecular weight of the polymer ebullioscopically obtained values indicating it to be a tetrameride. He studied the hydrolysis of the polymer with dilute acids and alkalis, and found that, although its aqueous solution did not contain any free hydrogen cyanide, the addition of mineral acids eliminated one molecule of hydrogen cyanide. With alkali, only 3 instead of 4 mols. of ammonia were evolved, aminoacetic, oxalic, and carbonic acids being formed. He concluded from these results that the polymer was the hydrocyanide of aminomalononitrile. This and subsequent work are not mentioned by Taylor and Baker (Sidgwick's "Organic Chemistry of Nitrogen," 1937, 307), who still regard the polymer as aminomalononitrile.

The formation of oxalic and carbonic acids as hydrolytic products was a serious obstacle to this view. Bedel suggested that the oxalate was produced by the prolonged interaction between the formate and carbonate first produced during the hydrolysis. This view is, however, untenable since aqueous solutions of formates and carbonates do not react in this manner, and furthermore, it has since been found that the formation of oxalate is immediate, and the amount produced is not increased by prolonged boiling. Grischkevitsch-Trochimovski later (*Rocz. Chem.*, 1928, **8**, 165) assumed the compound to be a tetrameride, without explaining the discrepancies in his former paper, and claimed to have obtained dicyanopyrazine from its condensation with glyoxal. From this result he considered that the

(I.) $\begin{array}{l} NH_2\cdot C\cdot CN \\ \quad\;\, \| \\ NH_2\cdot C\cdot CN \end{array}$



(II.)

polymer must be diaminomaleinitrile (I), his claim, however, resting on the m. p. of the dicarboxylic acid obtained by the hydrolysis of the dicyanopyrazine; but the constitution of the acid was not proved. He also suggested the following scheme for the hydrolysis of the polymer:

$$\begin{array}{l} CN\cdot C\cdot NH_2 \\ \quad\;\;\| \\ CN\cdot C\cdot NH_2 \end{array} + HOH \longrightarrow \begin{array}{l} HO\cdot C\cdot NH_2 \\ \quad\;\;\| \\ CN\cdot C\cdot NH_2 \end{array} \xrightarrow{H_2O} \begin{array}{l} HO\cdot CO\cdot NH_2 \longrightarrow CO_2 + NH_3 \\ \quad\;\; + \\ CO_2H\cdot CH_2\cdot NH_2 + NH_3 \end{array}$$

In this scheme Grischkevitsch-Trochimovski considers the double bond as the initial point of attack, which is contrary to the general behaviour of methyl-, amino-, and hydroxymaleic acids, all of which are stable to boiling alkalis; furthermore, he overlooks the formation of oxalic acid. Another serious objection to the diamino-structure for the polymer lies in its behaviour with aldehydes. It has been shown (Ladenburg, *Ber.*, 1878, **11**, 590, 1648; Weil and Marcinkowska, *Rocz. Chem.*, 1934, **14**, 1312) that *o*-diamines react with two molecules of an aldehyde forming a heterocyclic product (II), yet according to Grischkevitsch-Trochimovski (*loc. cit.*) the polymer gives rise to an open-chain derivative of a tripolymer.

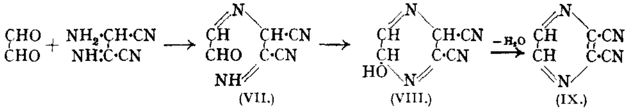
Although the mechanism of the polymerisation of hydrogen cyanide is not yet fully understood, it would appear to proceed in stages through the final addition of a hydrogen cyanide molecule to an intermediate tripolymer which can be either (III) or (IV) (cf. Wippermann, *loc. cit.*). The tetrapolymer could therefore have the structure (V) or (VI).

$NH_2\cdot CH{<}^{CN}_{CN}$	$NH_2\cdot CH{<}^{CN}_{NC}$	$\begin{array}{l} NH_2\cdot CH\cdot CN \\ NH{:}C\cdot CN \end{array}$	$\begin{array}{l} NH_2\cdot CH\cdot CN \\ \quad\;\; N{:}CH\cdot CN \end{array}$
(III.)	(IV.)	(V.)	(VI.)

The diaminomaleinitrile structure (I) cannot be considered as a possibility in this connection since it necessitates the migration of a hydrogen atom during the addition of the last molecule of hydrogen cyanide, and there seems no valid reason for this supposition,* nor is there any evidence that the polymer acts tautomerically.

Although the aminoiminosuccinonitrile (V) formula seemed the more probable, that represented by (VI), which contains the N·C·N·C— chain, could not be disregarded since it has been shown (Hinkel and Dunn, J., 1930, 1834) that when hydrogen chloride reacts with hydrogen cyanide, a compound is formed which also possesses the alternating carbon and nitrogen structure. Differentiation between these two structures should be readily achieved from a study of the condensation of the polymer with glyoxal, since a structure represented by (V) should give rise to a pyrazine derivative whereas the compound (VI) containing the N·C·N·C— chain could only give rise to pyrimidine derivatives.

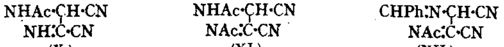
The properties of the dicarboxylic acids of pyrazine and pyrimidine are similar in many respects, and the m. p. upon which Grischkevitsch-Trochimovski relied is not sufficient evidence to decide between the two constitutions, especially as pyrimidine-2 : 4-dicarboxylic acid, which could result from (VI), is not known. The condensation of the polymer with glyoxal has therefore been re-investigated. Glyoxal in aqueous or alcoholic solution condenses readily with the polymer at ordinary temperatures to an orange-coloured product, $C_6H_4ON_4$ (Grischkevitsch-Trochimovski could not have employed pure polymer since he obtained a dark mass which he did not analyse). The primary reaction may be regarded as condensation of the amino-group with one aldehyde group, followed by ring formation, the first product being probably *6-hydroxy-2 : 3-dicyanodihydropyrazine* (VIII). This compound cannot be the open-chain compound (VII) with a free aldehyde group, since it does not react with phenylhydrazine. It can, however, be readily converted into a compound identical with the cyanopyrazine described by Grischkevitsch-Trochimovski, which has now been definitely characterised as 2 : 3-dicyanopyrazine by conversion into the corresponding dicarboxylic acid and into the parent base through its mercuric chloride salt. All these derivatives have been identified through authentic specimens prepared from quinoxaline (Gabriel and Sohn, *Ber.*, 1907, **40**, 4850). These results, which



(VII.) (VIII.) (IX.)

definitely dispose of the possible structure (VI), give strong support for the aminoiminosuccinonitrile structure (V) for the polymer, and this structure has been confirmed by a further study of the properties and reactions. The polymer unites with only one molecule of hydrogen chloride, a reaction which affords evidence, not only that the polymer is a tetrameride, but also that it does not possess two amino-groups, since all aliphatic diamines are strongly dibasic and yield dihydrochlorides. Moreover, the polymer readily condenses with one molecule of monoaldehydes, yielding open-chain *compounds* of the type $R{\cdot}CH{:}N_4C_4H_3$, contrary to Grischkevitsch-Trochimovski's observations (*loc. cit.*). In no circumstances has it been found possible to obtain a heterocyclic product characteristic of *o*-diamines (Ladenburg, *loc. cit.*).

With acetic anhydride the polymer first yields a *monoacetyl* derivative (X), which on more vigorous acetylation is converted into a *diacetyl* derivative (XI). In this reaction



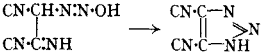
(X.) (XI.) (XII.)

also, no evidence has been found for the formation of heterocyclic ring compounds characteristic of *o*-diamines (cf. Hübner, *Annalen*, 1881, **208**, 278).

Although the *benzylidene* derivative does not unite with a second molecule of benzaldehyde, yet on vigorous acetylation it yields an *acetyl* derivative (XII). The polymer condenses readily with *o*-diketones such as diacetyl and benzil, yielding 2 : *3-dicyano-5 : 6-dimethyl-* and *-diphenyl-pyrazine* respectively. In these two cases in which ring formation

is possible, the pyrazine derivatives are formed without the intermediate stage (compare glyoxal). The constitution of the former compound was established by hydrolysis to dimethylpyrazinedicarboxylic acid (Gabriel and Sohn, *loc. cit.*).

It has been shown (Grischkevitsch-Trochimovski, *Rocz. Chem.*, 1921, **1**, 469) that the polymer readily reacts with nitrous acid, yielding a triazole in the manner of *o*-diamines (cf. Ladenburg, *loc. cit.*). The formation of a triazole can be equally well explained on the aminoiminosuccinonitrile structure, diazotisation of the amino-group being followed by ring closure (XIII):

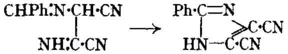


(XIII.)

The constitution of the triazole has been established by hydrolysis into 1 : 2 : 3-triazole-4 : 5-dicarboxylic acid (Bladin, *Ber.*, 1893, **26**, 545, 2737).

Grischkevitsch-Trochimovski (*J. Soc. Phys. Chim. Russ. Univ. Leningrad*, 1924, **55**, 548) and Fialkoff (*Bull. Soc. chim.*, 1927, **41**, 1209) claim to have obtained a yellow and a colourless variety of the dicyanotriazole possessing different crystallographic forms, and different electrical conductivities in aqueous solution. We have found that when the pure colourless polymer is diazotised under diverse conditions only one variety of the triazole is obtained, which is colourless; when, however, a slightly coloured specimen of the polymer was employed, a coloured triazole was obtained, from which the colour could not entirely be removed by crystallisation. We are forced to conclude that both the above authors employed impure polymer in their investigations.

Conclusive evidence for the existence of only one amino-group in the polymer is furnished through the benzylidene derivative. This compound is unaffected by nitrous acid, but with nitrous fumes it is readily oxidised with ring closure into 4 : 5-*dicyano*-2-



(XIV.)

phenyliminazole (XIV), the constitution of which was determined by hydrolysis into the corresponding dicarboxylic acid and subsequent decarboxylation to 2-phenyliminazole (Maquenne, *Compt. rend.*, 1890, **111**, 742; *Ann. Chim.*, 1891, **24**, 542).

In marked contrast to the benzylidene derivative, the monoacetyl compound readily reacts with nitrous acid, yielding a mixture of dicyanotriazole and 4(or 5)*cyano*-1 : 2 : 3-*triazole*-5(or 4)-*carboxyamide*, both of these compounds being identified by hydrolysis into 1 : 2 : 3-triazole-4 : 5-dicarboxylic acid. In this reaction the mineral acid employed eliminates the acetyl group, and the liberated polymer then reacts with the nitrous acid with the formation of the triazole ring. During this reaction partial hydrolysis of a cyano-group is induced by the liberated acetic acid in conjunction with the hydrochloric acid, since the polymer does not yield any cyano-amide when diazotised under the same conditions.

Experimental.

The black product resulting from the polymerisation of dry liquid hydrogen cyanide with either ammonium or potassium cyanide was repeatedly extracted with ether. The crude, dark solid so obtained was purified from boiling water after decolorisation with animal charcoal. After repeated recrystallisation from water, the polymer was obtained as colourless needles, m. p. 181° (decomp.).

6-Hydroxy-2 : 3-dicyanodihydropyrazine.—Glyoxal (1·2 g.; 1 mol.), dissolved in warm water (20 c.c.), was added to the polymer (2 g.; 1 mol.) dissolved in hot water (50 c.c.), and the mixture gently warmed on the water-bath for 5 minutes; a red powder separated, which was purified by means of alcohol, separating as a red amorphous powder, decomposing at 240° without melting (Found: C, 48·5; H, 3·0; N, 37·2. $C_6H_4ON_4$ requires C, 48·7; H, 2·7; N, 37·7%). The *substance* is very slowly decomposed by boiling water, but readily dissolves in boiling water containing a little oxalic acid to a yellow solution from which, on cooling, dicyanopyrazine separates as colourless needles, m. p. 132° (Found: C, 55·7; H, 1·5; N, 42·8. Calc.: C, 55·4; H, 1·3; N, 43·0%).

Hydrolysis of Dicyanopyrazine.—The finely powdered dicyanopyrazine (0·5 g.) was suspended in water (50 c.c.), and sodium peroxide (9 g.) slowly added with shaking until complete solution was obtained. After being heated on a water-bath for 2 hours, the mixture was acidified with nitric acid, and excess of silver nitrate added. The collected silver salt was decomposed with slight excess of hydrochloric acid, and the filtrate from the silver chloride evaporated to dryness under reduced pressure. The dark mass was dissolved in water, and the solution decolorised (charcoal) and concentrated; pyrazinedicarboxylic acid crystallised in colourless plates, m. p. 182—184° (decomp.), unchanged by admixture with an authentic specimen; the anhydrous acid melted at 193° (Gabriel and Sohn, *loc. cit.*, give for hydrated acid m. p. 186°, for anhydrous acid m. p. 193°).

Isolation of Base.—The above acid was decarboxylated with acetic anhydride, according to Gabriel and Sohn (*loc. cit.*). The resulting liquid, after being made alkaline with sodium hydroxide, was distilled into an aqueous solution of mercuric chloride. The resulting white mercurichloride of the base, after being washed with alcohol and ether, melted at 272° (cf. Stoehr, *J. pr. Chem.*, 1895, **51**, 457), unchanged by admixture with an authentic specimen prepared according to Gabriel and Sohn. The mercuric salt (2 g.) was added to saturated solution of sodium sulphide (4 c.c.), and the mixture distilled. The distillate (2 c.c.) was cooled in ice and salt, and solid sodium hydroxide added to precipitate the free base, which was then extracted with the minimum amount of ether. From the dried ethereal solution the base was obtained by rapid evaporation of the ether on a water-bath; the cooled residue solidified, m. p. 52°, unchanged when admixed with an authentic specimen of pyrazine prepared from quinoxaline according to Gabriel and Sohn (*loc. cit.*).

Aminoiminosuccinonitrile Hydrochloride.—The powdered polymer was dissolved in dry ether, and the solution saturated with dry hydrogen chloride. The white *hydrochloride* which was deposited was washed with ether and dried in a vacuum over sulphuric acid; decomp. 135° (Found: C, 33·15; H, 3·5; N, 38·1; Cl, 24·5. $C_4H_4N_4$,HCl requires C, 33·3; H, 3·4; N, 38·8; Cl, 24·5%).

Compounds of Aminoiminosuccinonitrile with Aldehydes.—Molecular proportions of the polymer and the aldehydes in alcohol were heated under reflux for 30 minutes. The condensation products crystallised on cooling, and were purified by crystallisation from alcohol. *Benzylideneaminoiminosuccinonitrile*, yellow needles, m. p. 191° (decomp.) (Found: C, 67·1; H, 4·1; N, 28·5. $C_{11}H_8N_4$ requires C, 67·3; H, 4·1; N, 28·6%). *Salicylideneaminoiminosuccinonitrile*, yellow needles with a greenish tinge, m. p. 234° (decomp.) (Found: N, 26·7. $C_{11}H_8N_4$ requires N, 26·4%). m-*Bromosalicylideneaminoiminosuccinonitrile*, yellow needles, m. p. above 250° (Found: N, 28·5; Br, 27·5. $C_{11}H_7ON_4Br$ requires N, 28·6; Br, 27·5%). *Anisylideneaminoiminosuccinonitrile*, yellow needles, m. p. 227° (decomp.) (Found: N, 24·9. $C_{12}H_{10}ON_4$ requires N, 24·8%). iso*Butylideneaminoiminosuccinonitrile*, colourless laminæ, m. p. 91° (decomp.) (Found: C, 58·1; H, 6·15. $C_8H_{10}N_4$ requires C, 58·4; H, 6·17%). In none of the above condensations was it possible to cause reaction with a second molecule of aldehyde.

Acetamidoiminosuccinonitrile.—The polymer (1 g.) was gently warmed with acetic anhydride (2 c.c.), in which it dissolved. On cooling, crystals slowly separated (1·4 g.) which, after being decolorised with charcoal, crystallised from alcohol in colourless needles, m. p. 164° (decomp.) (Found: C, 47·8; H, 3·9; N, 36·6. $C_6H_6ON_4$ requires C, 48·0; H, 4·0; N, 37·3%).

Acetamidoacetimidosuccinonitrile.—The polymer (1 g.) and acetic anhydride (5 c.c.) were heated on a water-bath for 30 minutes. The excess of anhydride was removed at 100° under reduced pressure. The product (1·8 g.), after being decolorised, crystallised from alcohol in colourless needles, m. p. 224° (decomp.) (Found: C, 50·0; H, 4·2; N, 30·0. $C_8H_8O_2N_4$ requires C, 50·0; H, 4·2; N, 29·2%).

Benzylideneaminoacetimidosuccinonitrile.—A mixture of the benzylidene derivative of the polymer (2 g.) and acetic anhydride (10 c.c.) was heated to boiling for 45 minutes, and the excess of anhydride removed under reduced pressure. The residue (1·8 g.), after being decolorised, separated from alcohol as a colourless crystalline powder, m. p. 227° (decomp.) (Found: C, 65·9; H, 4·37; N, 23·6. $C_{13}H_{10}ON_4$ requires C, 65·55; H, 4·2; N, 23·5%).

2 : 3-*Dicyano*-5 : 6-*dimethylpyrazine.*—Molecular proportions of diacetyl and of the polymer in alcohol were heated for 2 hours on a water-bath. The solid which separated crystallised from alcohol–acetone and yielded 2 : 3-*dicyano*-5 : 6-*dimethylpyrazine* in large white laminæ, m. p. 171° (Found: C, 60·5; H, 3·8. $C_8H_6N_4$ requires C, 60·7; H, 3·8%).

2 : 3-*Dicyano*-5 : 6-*diphenylpyrazine.*—The condensation of benzil with the poylmer was carried out as above. The product, crystallised from alcohol–benzene, gave 2 : 3-*dicyano*-5 : 6-

diphenylpyrazine as colourless prisms, m. p. 246° (Found : C, 76·3; H, 3·6; N, 19·5. $C_{18}H_{10}N_4$ requires C, 76·6; H, 3·5; N, 19·9%).

Hydrolysis of 2 : 3-*Dicyano*-5 : 6-*dimethylpyrazine*.—The powdered substance (12 g.) was suspended in water (120 c.c.), and sodium peroxide (24 g.) gradually added with shaking until complete solution was effected. The mixture was then heated on a water-bath for 3 hours until evolution of ammonia ceased; it was then acidified with glacial acetic acid and concentrated to 50 c.c. Addition of barium chloride precipitated the barium salt, which was washed and dried; the powdered salt (20 g.) was made into a paste with water (45 c.c.), and sulphuric acid monohydrate (6 g.) added, the mixture being heated on a water-bath for 1 hour. The filtered solution was evaporated to dryness under reduced pressure. The residue (9 g.) crystallised from hot water, yielding 2 : 3-dimethylpyrazine-5 : 6-dicarboxylic acid in colourless needles, m. p. (anhydrous acid) 200° (Found : C, 48·0; H, 4·2. Calc. : C, 48·9; H, 4·1%).

Action of Nitrous Acid on Aminoiminosuccinonitrile.—Pure colourless polymer (2·16 g.) was suspended in water (50 c.c.), in which sodium nitrite (1·38 g.) was dissolved, and cooled in ice; 4*N*-hydrochloric acid (5 c.c.) was then gradually added with stirring. The polymer readily dissolved, and the reaction was completed by warming on a water-bath. The cooled solution was extracted with ether. Removal of the ether yielded 4 : 5-dicyano-1 : 2 : 3-triazole entirely devoid of any yellow tinge; it crystallised from alcohol in transparent prisms, m. p. 145°.

Hydrolysis of 4 : 5 *Dicyano*-1 : 2 : 3-*triazole*.—The powdered triazole (2 g.) was suspended in water (100 c.c.), and sodium peroxide added in small quantities until the precipitate first formed redissolved. The mixture was then heated on a water-bath until evolution of ammonia had ceased (1 hour), acidified with hydrochloric acid, and well cooled (ice–salt). The white precipitate so obtained (2·39 g.) was crystallised from dilute hydrochloric acid and finally from hot water. 1 : 2 : 3-Triazole-4 : 5-dicarboxylic acid crystallised in colourless laminæ, m. p. 200° (decomp.), unchanged by admixture with an authentic specimen prepared by oxidation of aziminobenzene (Bladin, *loc. cit.*).

Action of Nitrous Acid on Acetamidoiminosuccinonitrile.—A solution of sodium nitrite (1 g.) in water (5 c.c.) was slowly added to a suspension of finely powdered acetamidoiminosuccinonitrile (4 g.) in water (20 c.c.) and 4*N*-hydrochloric acid (4 c.c.). The solution was kept stirred, and warmed to 40° to complete the reaction. The solution was cooled to 0°, and the white solid filtered off (filtrate A). Crystallisation from alcohol yielded 4(or 5)-*cyano*-1 : 2 : 3-*triazole*-5(or 4)-*carboxyamide* in colourless needles, m. p. 219° (decomp.) (Found : C, 34·7; H, 2·26; N, 50·8. $C_4H_3ON_5$ requires C, 35·4; H, 2·2; N, 51·0%); this is strongly acid in solution, being soluble in alkali and reprecipitated by acids; hydrolysis with sodium peroxide as above yields 1 : 2 : 3-triazole-4 : 5-dicarboxylic acid.

The filtrate A was extracted with ether, the extract dried (sodium sulphate), and the ether removed, yielding 4 : 5-dicyano-1 : 2 : 3-triazole (1·6 g.), m. p. 145°, unchanged by admixture with the compound prepared as above.

Oxidation of Benzylideneaminoiminosuccinonitrile.—Nitrous fumes were led into a solution of the nitrile (2 g.) in ether (200 c.c.) until a yellow solid separated; the filtrate from the solid on concentration gave a further yield (total 1·8 g.). The solid was crystallised from alcohol, and 4 : 5-*dicyano*-2-*phenyliminazole* separated as minute, cream-coloured needles, m. p. 261° (decomp.) (Found : C, 68·3; H, 3·0; N, 28·55. $C_{11}H_6N_4$ requires C, 68·05; H, 3·1; N, 28·3%).

Hydrolysis of 4 : 5-*Dicyano*-2-*phenyliminazole*.—The iminazole (7 g.) was added to caustic soda (7 g.) in alcohol (40 c.c.) and heated under reflux for 1 hour. After removal of the alcohol, the residue was dissolved in water, and 2-phenyliminazole-4 : 5-dicarboxylic acid (7·2 g.) precipitated with hydrochloric acid. It was purified by dissolution in alkali and reprecipitation with acid; m. p. 243—244° (Maquenne, *loc. cit.*, does not record m. p.). Dry distillation of the acid under reduced pressure yielded phenyliminazole as a colourless liquid, which solidified to white crystals, m. p. 147—148° (compare Maquenne, *loc. cit.*).

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UNIVERSITY COLLEGE, SWANSEA. [*Received, June 18th, 1937.*]

296. *The Reaction between Aqueous Silver Nitrate and Cuprous Thiocyanate. An Indirect Argentometric Method for the Determination of Copper and a "Spot" Test for Silver.*

By Vincent J. Occleshaw.

The reaction between cuprous thiocyanate and aqueous silver nitrate has been studied for comparison with those of the cuprous halides, and as a possible volumetric method for determining copper. It has been found that two mols. of silver nitrate react with one of cuprous thiocyanate to produce a smoky-brown residue, which is shown to be an equimolecular mixture of finely divided silver with silver thiocyanate. Hence, cuprous thiocyanate and the cuprous halides react similarly with aqueous silver nitrate. This reaction can be used as an argentometric method for determining copper, the determination being carried out in neutral or ammoniacal solution. The conditions under which the cuprous salt is precipitated prevent interference by mercury, and silver in moderate amount does not interfere. The reaction has been developed as a "spot" test for silver.

If a thiocyanate is titrated with silver nitrate in presence of cuprous thiocyanate and an adsorption indicator, the colour assumed by the precipitate at the end-point disappears on standing. When cuprous thiocyanate is treated with aqueous silver nitrate it assumes a smoky-brown colour, and the supernatant liquid develops the colour and shows the reactions of bivalent copper. The residue gives reactions for silver and silver thiocyanate. With cuprous thiocyanate in excess it is possible to replace silver completely by copper, and *vice versa*. A quantitative examination of this reaction showed that 1 mol. of cuprous thiocyanate reacts with 2 of silver nitrate, and that the residue contains 1 atom of silver which can be dissolved out by dilute nitric acid, leaving 1 mol. of silver thiocyanate. A similar result is obtained by repeatedly extracting the residue with ammonium hydroxide to dissolve out the thiocyanate. Hence, the residue is either the sub-salt, Ag_2NCS, or an equimolecular mixture of silver thiocyanate with finely divided silver.

Vogel (*Phot. Mitt.*, 1899, **36**, 344) found that cuprous halides react with aqueous silver nitrate, producing similarly coloured residues which he considered to be silver sub-halides, but further examination of these substances showed that they are probably mixtures of normal halides with finely divided silver (Emszt, *Z. anorg. Chem.*, 1901, **28**, 346; Waterhouse, *Phot. J.*, 1900, **24**, 156). The evidence for the existence of other silver sub-salts is unsatisfactory.

X-Ray powder photographs of an air-dried sample of the smoky-brown residue show 11 rings with diameters characteristic of silver, and another 10 with diameters identical with those given by silver thiocyanate. Nevertheless, it has not been possible to effect a satisfactory separation of the constituents of the mixture by flotation, and only prolonged treatment of the residue with mercury extracts any silver. In addition, when the undried residue is soaked in ammonium hydroxide (1 : 1) for 2 days, only part of the silver thiocyanate dissolves.

It follows that the reaction of cuprous thiocyanate with aqueous silver nitrate is similar to that of the cuprous halides. This reaction is relatively slow at room temperature, but is accelerated by heating, about 2 hours' gentle boiling being needed to make 0·25 g. of dry, finely divided cuprous thiocyanate react completely. The rate also depends on the state of division of the cuprous salt, and freshly filtered, undried material is more reactive than the dried substance: 0·25 g., when added to excess of boiling silver nitrate, needs about 30 minutes for complete reaction.

When the reaction was used to determine copper volumetrically, the maximum error in 14 determinations with 0·3-g. samples of crystalline copper sulphate was $\pm$ 0·26% and in 22 determinations on 0·5-g. quantities $\pm$ 0·36%. Mercury is not precipitated under the conditions used to precipitate cuprous thiocyanate. Silver in moderate quantity does not interfere, and with an atomic ratio Ag : Cu = 2 : 1, the maximum error in 8 determinations was $\pm$ 0·30%.

This is a somewhat simpler argentometric method for determining copper than that proposed by Biazzo and Tanteri (*Ann. Chim. appl.*, 1935, **25**, 44), but it is possible to adapt the latter method to deal with cuprous thiocyanate, and a maximum error of $\pm$ 0·45% was obtained in 11 determinations of copper sulphate.

By using this reaction as a "spot" test for silver, it is possible to detect in bright daylight as little as 2·2γ of silver, and in sunlight 1·1γ, in one drop (0·05 ml.) of solution. If the test is carried out in a small tube with 0·5 ml. of solution, silver can be detected in a 0·0004*M*- or a 0·0001*M*-solution in bright daylight or in sunlight respectively. Lead neither interferes with nor reduces the sensitivity of the test, and interference by mercury can easily be overcome. Nitric acid in moderate concentration does not interfere.

EXPERIMENTAL.

"AnalaR" Chemicals were used without further purification. Cuprous thiocyanate was made as required by using hydroxylamine as reducing agent; it was filtered on to a layer of macerated filter-paper supported on a pad of glass-wool in a Gooch crucible. (With asbestos as filtration medium more silver nitrate was subsequently used than corresponds to theory.) When required dry, the cuprous salt was washed with alcohol and dried in an air oven at 120—130°.

Silver was determined by Volhard's method, the following standardised conditions being maintained throughout. To the silver nitrate were added 10 ml. of concentrated nitric acid, 4 ml. of a saturated solution of ferric alum, and sufficient water to make the volume up to 200 ml. As Holwech (*Tidsskr. Kjemi*, 1930, **10**, 78) reported that the presence of copper interferes with the end-point, blanks were determined, 25 ml. and 50 ml. of silver nitrate being used with addition of 0·3 g. or 0·5 g. of crystalline copper sulphate. The corrections found were 0·05 and 0·08 ml., respectively, of 0·1*N*-ammonium thiocyanate and these were applied throughout this work. Determination of copper, when required, was carried out iodometrically. In the determination of silver thiocyanate by potassium iodate, results, based on the iodate weighed out, are lower than theory by as much as 1%, so the iodate was standardised against silver thiocyanate obtained from known volumes of a standard solution of the ammonium salt. Undried silver thiocyanate reacts rapidly. The low results obtained are thought to be due to inability to wash nitric acid completely out of the precipitate. When ammonium thiocyanate is determined with iodate in presence of small amounts of nitric acid, low results are obtained, as shown by the following data: 10 Ml. of ammonium thiocyanate required 14·65 ml. of iodate; with addition of 1 ml. or of 0·2 ml. of *N*-nitric acid the titre decreased to 13·45 ml. or 14·15 ml., respectively, and even with 0·1 ml. of acid the titre was only 14·45 ml., or still 1·4% low.

Examination of the Reaction.—(a) *Qualitatively.* 0·5 G. of cuprous thiocyanate was boiled with 150 ml. (excess) of silver nitrate for 2 hours and the residue separated. Part of this was heated with dilute nitric acid (1 : 1) until no further colour change occurred; the remaining solid was filtered off, and dissolved by long boiling with nitric acid. The rest of the residue was exhaustively extracted with ammonia, and the residual grey solid dissolved in nitric acid. The resultant acid and ammoniacal solutions were submitted to qualitative tests.

(b) *Quantitatively.* 0·25 G. lots of cuprous thiocyanate, or the undried precipitates of thiocyanate resulting from 0·3—0·5 g. portions of crystalline copper sulphate, were boiled with 50 ml. or 75 ml. of standard silver nitrate for 1—2 hours, filtered, and excess silver nitrate determined. Then in a few cases copper was also determined. Silver was dissolved out of the residue by heating on a water-bath for ½ hour with nitric acid (*d* 1·12), which does not attack silver thiocyanate, and determined; the silver thiocyanate in the remaining solid was also determined.

Determination of Copper Argentometrically.—The known weights of crystalline copper sulphate were converted into cuprous thiocyanate by Krauss's procedure (*Z. angew. Chem.*, 1927, **40**, 354). The precipitate and filter were added to a suitable volume of standard silver nitrate, previously made air free, and boiled gently for ½ hour, or an hour if the thiocyanate had stood overnight prior to filtration. After separation of the residue, excess silver nitrate was determined.

Modification of Biazzo and Tanteri's Method.—The apparatus was substantially that used by these authors (*loc. cit.*). A convenient volume of standard silver nitrate was made air free, the cuprous thiocyanate and filter added, and boiling continued for a few minutes, after which the closed flask was cooled by immersion in water. Then 10 ml. of concentrated ammonia were added without access of air, and the closed flask was heated on a water-bath for 15 minutes.

Finely divided silver was filtered off, well washed with dilute ammonia, and excess silver nitrate determined.

"Spot" Test for Silver.—A thin circular smear of freshly filtered cuprous thiocyanate was placed on filter-paper or porcelain, and the test solution dropped on it. The development of a brown coloration, changing to grey, was observed in the course of a few seconds. If porcelain was used, and the smear was exposed for 15 seconds 3″ below a 250-watt lamp with reflector, the sensitivity was the same as in daylight. Since much of the effectiveness of this test is lost unless the development of the coloration can be observed, no other artificial light sources were used. The test solution was also shaken in a small tube with a little undried cuprous salt; addition of too much cuprous salt retards the colour change. With the more dilute solutions the coloration tends to disappear on long exposure.

Moist cuprous thiocyanate alone was found to be non-sensitive to light under the conditions specified, and when solid ammonium thiocyanate was substituted for the cuprous salt, tests were negative even with 0·1*M*-silver nitrate.

Interference.—With 0·0004*M*-silver solutions the test was positive in sunlight so long as the concentration of nitric acid did not exceed 1·4*N*, but in a small tube the test failed when this concentration became greater than 0·5*N*. With sulphuric acid up to *N* instead of nitric acid, positive results were obtained. In a small tube a retardation in the rate of colour formation was noticeable, greater in the case of nitric acid, as the acid concentration increased. The more pronounced interference by nitric acid may be due to its greater solvent action on finely divided silver.

Dilute solutions of mercuric nitrate give a greenish-yellow coloration with a smear of cuprous thiocyanate. The mercury in a solution obtained by mixing 10 ml. of 0·1*M*-mercuric nitrate with 4 ml. of 0·01*M*-silver nitrate was precipitated by careful addition of ammonia, and filtered off. The ammoniacal silver solution was just acidified with acetic acid and diluted to 100 ml.; it then gave a positive test.

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THE UNIVERSITY OF LIVERPOOL. [*Received, June 24th*, 1937.]

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297. *Derivatives of 4-cycloHexyldiphenyl. Part III.*

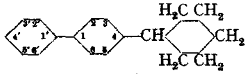
By F. ROBERT BASFORD.

Nitration of 4-*cyclo*hexyldiphenyl affords, according to the conditions used, either the 2- and the 4′-nitro-derivative, or a trinitro-compound. Both the mononitro-compounds give the corresponding amine on reduction, and the corresponding nitro-1 : 4-diphenylbenzene on dehydrogenation by means of bromine. 2-Nitro-1 : 4-diphenylbenzene has been reduced to the amine.

4 : 4′-Di*cyclo*hexyldiphenyl, on nitration in acetic acid solution, affords a dinitro-compound, which has been reduced to the corresponding diamine.

Among other compounds described are 4′-bromo- and 4′-*p*-nitrobenzoyl-4-*cyclo*-hexyldiphenyl and 4-*cyclo*hexyldiphenyl-4′-carboxylyl chloride.

WHEN 4-*cyclo*hexyldiphenyl (I) is nitrated in acetic acid solution, both homo- and hetero-nuclear nitration occur, just as in the case of 4-methyldiphenyl (Grieve and Hey, J.,



(I.)

1932, 1888). The 2- and the 4′-*nitro*-derivative are formed in the approximate ratio of 2 : 1, together with some 4-nitrodiphenyl and oily products. If the nitric acid is not diluted with acetic acid, a *trinitro*-derivative is formed.

The constitution of the 2-nitro-4-*cyclo*hexyldiphenyl was proved by (a) oxidation with chromic acid to 2-nitrodiphenyl-4-carboxylic acid (Grieve and Hey, *loc. cit.*), (b) reduction

with stannous chloride and hydrochloric acid or iron and hydrochloric acid to the corresponding *amine*, and (c) dehydrogenation with bromine at 180—200° to 2-*nitro*-1 : 4-*diphenylbenzene*. The 4′-nitro-derivative yielded a similar series of compounds, and in addition its constitution was proved by its conversion into 4′-bromo-4-*cyclo*hexyldiphenyl (J., 1936, 1780) through the *diazonium perbromide*, prepared from 4′-amino-4-*cyclo*hexyldiphenyl, characterised as its *hydrochloride*.

Nitration of 4 : 4′-di*cyclo*hexyldiphenyl in acetic acid solution gives a *dinitro*-compound, which is reduced with iron and hydrochloric acid to the corresponding *diamine*.

Other compounds obtained are mentioned in the foregoing summary.

Experimental.

2-*Nitro*-4-cyclo*hexyldiphenyl*.—4-*cyclo*Hexyldiphenyl (6 g.), dissolved in glacial acetic acid (12 c.c.), was nitrated with a mixture of 7 c.c. of nitric acid (*d* 1·488) and 3 c.c. of glacial acetic acid. The temperature, initially at 65°, rose rapidly when nitration set in, and cooling was necessary. The remaining acid was then run in, and the solution kept at 85° during 10 minutes; on cooling, 4·4 g. of crystalline material were deposited, m. p. 125—145°. Recrystallised from alcohol–acetone (6 : 1), this gave pale yellow needles (3 g.), m. p. 164·5° (sharp) (Found : N, 5·3. $C_{18}H_{19}O_2N$ requires N, 4·98%).

Oxidation of 2-*Nitro*-4-cyclo*hexyldiphenyl to* 2-*Nitrodiphenyl*-4-*carboxylic Acid*.—A solution of chromic anhydride (2·5 g.) in glacial acetic acid (25 c.c.) was added to 2-nitro-4-*cyclo*hexyldiphenyl (0·5 g.) dissolved in 15 c.c. of glacial acetic acid. The mixture was boiled during 1 hour and then diluted with water; the acid was extracted with ether and purified by dissolution in sodium carbonate solution and reprecipitation with hydrochloric acid. The product crystallised from alcohol in pale yellow needles, m. p. 191°, undepressed on admixture with authentic 2-nitrodiphenyl-4-carboxylic acid, kindly supplied by Dr. Hey, of Manchester University.

2-*Amino*-4-cyclo*hexyldiphenyl*.—(a) The nitro-compound was dissolved in hot alcohol, and the solution added to stannous chloride dissolved in concentrated hydrochloric acid. The stannichloride of the base separated, and the reaction was completed by warming the mixture until a clear solution resulted; this was treated with an excess of dilute alkali, and the free base extracted with ether. Evaporation of the ethereal solution left a product which recrystallised from aqueous alcohol in colourless plates, m. p. 102°.

(b) Iron filings and concentrated hydrochloric acid were added to a solution of the nitro-compound in alcohol. After the reaction was completed, most of the alcohol was distilled off, and the hydrochloride of the base separated from the cooled solution; it was filtered off, and washed with hydrochloric acid until free from all traces of ferric chloride. Colourless needles were obtained; the free *base*, liberated by suspending the hydrochloride in dilute ammonia, was recrystallised from aqueous alcohol; m. p. 102° (Found : N, 5·3. $C_{18}H_{21}N$ requires N, 5·58%).

The *acetyl* derivative was prepared by refluxing a toluene solution of the amine with acetic anhydride for 8 hours; the toluene was removed by steam-distillation, the solid product separated, and crystallised from dilute alcohol; colourless rhombohedral crystals were obtained, m. p. 116° (Found : N, 4·9. $C_{20}H_{23}ON$ requires N, 4·78%). The *benzoyl* derivative, prepared by the Schotten–Baumann method, crystallised from alcohol; m. p. 158° (Found : N, 3·9. $C_{25}H_{25}ON$ requires N, 3·94%).

2-*Nitro*-1 : 4-*diphenylbenzene*.—2-Nitro-4-*cyclo*hexyldiphenyl was melted at 165°, and bromine added during 15 minutes. The temperature was raised to 180° and maintained thereat during 15 minutes, and the reaction was completed by warming for a short time at 200°. The product was extracted with acetone, most of the material remaining undissolved; this crystallised from alcohol in almost colourless plates, m. p. 125° (Found : N, 5·1. $C_{18}H_{13}O_2N$ requires N, 5·09%).

2-*Amino*-1 : 4-*diphenylbenzene*.—A solution of the nitro-compound in alcohol was added gradually to stannous chloride dissolved in hydrochloric acid. The mixture was warmed until it formed a clear solution; dilute sodium hydroxide was added, and the base extracted with ether. Evaporation of the ethereal extract left a product which crystallised from alcohol as colourless plates, m. p. 169° (Found : N, 6·0. $C_{18}H_{15}N$ requires N, 5·71%). The *benzoyl* derivative, prepared in the usual way, crystallised from alcohol as colourless needles, m. p. 144° (Found : N, 4·1. $C_{25}H_{19}ON$ requires N, 4·11%).

4′-Nitro-4-cyclo*hexyldiphenyl*.—The mother-liquors from the crystallisation of the product obtained by the nitration of the parent hydrocarbon were evaporated, and on cooling, pale yellow, long, narrow plates were deposited, m. p. 124° (Found: N, 5·0. $C_{18}H_{19}O_2N$ requires N, 4·98%).

Oxidation of 4′-*Nitro*-4-cyclo*hexyldiphenyl to* 4-*Nitrodiphenyl*-4′-*carboxylic Acid*.—A suspension of the nitro-derivative in a solution of sodium dichromate in water and acetic acid was treated with concentrated sulphuric acid. Oxidation was not very ready, and the mixture was boiled for 1 hour; water was added, and a precipitate separated. This was stirred into dilute aqueous sodium hydroxide and filtered from some unchanged nitro-compound; the filtrate, treated with hydrochloric acid, gave an organic acid which sublimed in white plates, m. p. 340°, not depressed by admixture with authentic 4-nitrodiphenyl-4′-carboxylic acid.

4′-Amino-4-cyclo*hexyldiphenyl*.—The nitro-compound was reduced by the same methods as were employed for the preparation of the 2-amino-isomer; the free base separated from aqueous alcohol in an amorphous form. It was analysed as the *hydrochloride*, which melted to a cloudy liquid at 90° and became clear at 110° (Found: N, 4·7. $C_{18}H_{21}N,HCl$ requires N, 4·87%).

The *acetyl* derivative was prepared by refluxing a suspension of the amine in a mixture of water, acetic acid, and acetic anhydride during 3 hours; the solid was filtered off, dried, and crystallised from methyl alcohol; colourless plates, m. p. 225° (Found: N, 4·9. $C_{20}H_{23}ON$ requires N, 4·78%). The *benzoyl* derivative, prepared by the Schotten–Baumann reaction, crystallised from alcohol in colourless plates, m. p. 240° (Found: N, 3·8. $C_{25}H_{25}ON$ requires N, 3·94%).

4′-Nitro-1 : 4-*diphenylbenzene*.—Bromine was dropped into 4′-nitro-4-*cyclo*hexyldiphenyl at 150° during 15 minutes; the product was then cooled, shaken with warm acetone, and filtered. The filtrate was boiled with charcoal, and the filtered solution deposited pale yellowish-brown plates, which, from alcohol–acetone, had m. p. 211° (Found: N, 5·0. $C_{18}H_{13}O_2N$ requires N, 5·09%).

4-cyclo*Hexyldiphenyl*-4′-*diazonium Perbromide*.—4′-Amino-4-*cyclo*hexyldiphenyl was suspended in 10% hydrochloric acid and diazotised by addition of solid sodium nitrite. The diazonium solution was filtered, and poured into a saturated solution of potassium bromide; the resulting yellow precipitate was separated, washed, and dried. Crystallisation from benzene–light petroleum afforded yellow needles, m. p. 105° (decomp.) (Found: Br, 48·0. $C_{18}H_{19}N_2Br_3$ requires Br, 47·72%).

4′-Bromo-4-cyclo*hexyldiphenyl*.—The diazonium perbromide was added to alcohol at 78°, and evaporation of the solution left a crystalline residue which recrystallised from alcohol in colourless plates, m. p. and mixed m. p. with authentic 4′-bromo-4-*cyclo*hexyldiphenyl, 154°.

Trinitro-4-cyclo*hexyldiphenyl*.—4-*cyclo*Hexyldiphenyl (2 g.) was added during ½ hour to 20 c.c. of concentrated nitric acid at 20°. The mixture was thoroughly stirred so that the hydrocarbon dissolved continuously, and the temperature rose to 35°. The *trinitro*-derivative separated on cooling (0·4 g.), and crystallised from alcohol–acetone in long needles, m. p. 235° (Found: N, 11·1. $C_{18}H_{17}O_6N_3$ requires N, 11·32%).

4′-(p-*Nitrobenzoyl*)-4-cyclo*hexyldiphenyl*.—(a) 4-*cyclo*Hexyldiphenyl and *p*-nitrobenzoyl chloride were dissolved in carbon disulphide; reaction was initiated by addition of aluminium chloride, and completed after 2 hours by warming at 50° during ½ hour. The product was decomposed with dilute acid, and the solvent removed by evaporation; the solid residue was extracted with three successive portions of dilute caustic alkali, and the nitro-compound filtered off. This was washed with water, dried, and recrystallised from benzene–light petroleum, forming a yellow, micro-crystalline powder (1·6 g.), m. p. 175°.

(b) 4′-Benzoyl-4-*cyclo*hexyldiphenyl was stirred into concentrated nitric acid at 0° during ½ hour; the temperature was then allowed to rise to 18°, and was maintained thereat for 1 hour. The product was separated by the addition of water, dried, and recrystallised as above, affording small crystals, m. p. and mixed m. p. with the previous preparation, 175° (Found: N, 3·8. $C_{25}H_{23}O_3N$ requires N, 3·66%).

4-cyclo*Hexyldiphenyl*-4′-*carboxylyl Chloride*.—4-*cyclo*Hexyl-4′-carboxylic acid was refluxed with thionyl chloride during 2 hours; the excess thionyl chloride was then removed by distillation, and the residue, a light-brown, crystalline mass, was recrystallised from light petroleum, from which pale yellow needles were obtained, m. p. 109° (Found: Cl, 12·3. $C_{19}H_{19}OCl$ requires Cl, 11·9%).

Dinitro-4 : 4′-*dicyclohexyldiphenyl*.—(a) 4 : 4′-Di*cyclo*hexyldiphenyl (1 g.) was stirred into 15 c.c. of concentrated nitric acid at 18°; the nitration was completed by heating at 40° until a clear solution was obtained (5 mins.). Water precipitated the *nitro-compound*, which was

separated, washed, and dried (1·25 g.); after two recrystallisations from alcohol, yellow needles, m. p. 182°, were obtained.

(b) The hydrocarbon (0·5 g.), dissolved in acetic acid (40 c.c.) at 70°, was nitrated by addition of a mixture of 10 c.c. each of fuming nitric acid and glacial acetic acid. The solution was diluted, and the filtered nitro-compound recrystallised from alcohol; yellow needles were deposited; m. p. and mixed m. p. with the product obtained in (a), 182° (Found: C, 70·0, H, 6·9. $C_{24}H_{28}O_4N_2$ requires C, 70·59, H, 6·86%).

*Diamino-4 : 4'-di*cyclo*hexyldiphenyl.*—The nitro-derivative was reduced in alcoholic solution with iron and hydrochloric acid; the solvent was distilled off, and the hydrochloride of the base separated from the cooled solution. This was extracted with ether in the presence of ammonia, and evaporation of the ethereal extract left the *diamine*, which crystallised from alcohol in pale buff-coloured needles, m. p. 225° (Found: N, 8·1. $C_{24}H_{32}N_2$ requires N, 8·05%).

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UNIVERSITY COLLEGE, NOTTINGHAM. [*Received, July 8th*, 1937.]

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298. *The Carbonyl Constituents of Eucalyptus Oils. Part II. The Seasonal Variation of* E. cneorifolia *Oil.*

By P. A. BERRY, A. KILLEN MACBETH, and T. B. SWANSON.

The oils obtained by monthly distillations of (*a*) old leaf and (*b*) young leaf and growing tips of *E. cneorifolia* were regularly examined with the object of searching for evidence of phytochemical synthesis of the components; and also of seeing if cryptal occurred in the oil at any season of growth.

The yield of young leaf oil increases during the period of active growth, and side by side with this a fall in the density and a rise in the *l*-rotation of the oil are observed, these changes being correlated with the increase in the terpene content of the oil. No marked similar change is found in the oils from old leaf.

The terpenes are found to contain considerable quantities of *l*-β-phellandrene during the flush period, and the biogenetic relationship *l*-β-phellandrene, *l*-phellandral, *l*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one is suggested. *l*-α-Phellandrene and cymene are also present in these oils, the cymene content decreasing in the winter months.

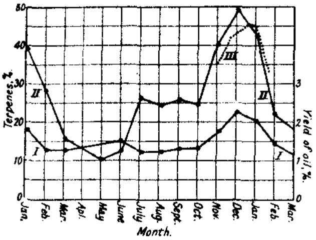
No cryptal was detected during the examination of upwards of fifty samples of the oils.

THE regular examination of the oil of *E. cneorifolia* was first undertaken in the hope that seasonal variation in the components would afford some evidence of phytochemical change on which biogenetic relationships might be based: and with the later object of also ascertaining if the aldehyde cryptal, previously reported, occurred in the oil at any period of the year. It now appears (this vol., p. 986) that the existence of cryptal was assumed in error, and the present examination of upwards of fifty samples of *E. cneorifolia* oil, which has extended over several years, has failed to disclose any proof of its existence.

The biogenesis of the constituents of essential oils has been discussed by, amongst others, Read (*J. Soc. Chem. Ind.*, 1929, **48**, 786; *Chem. Reviews*, 1930, **7**, 41) and Hall (*ibid.*, 1933, **13**, 479). The suggestions made have generally been based on the mutual occurrence of components, one of which, such as geraniol, may readily be shown to give rise to the formation of the others by a series of simple changes involving cyclisation, dehydration, hydration, and intramolecular change. The work now described gives results on which, we suggest, biogenetic relationships may more confidently be based.

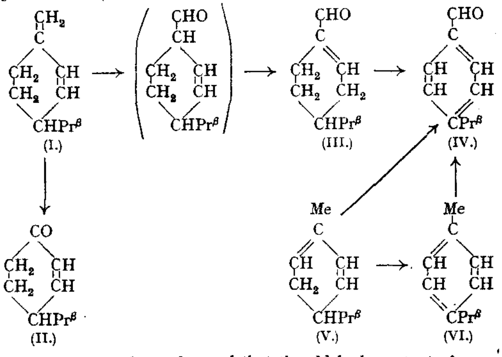
The examination of *E. cneorifolia* oil obtained by monthly distillations of old leaf showed no marked change in the nature of the components or in their amounts throughout the year. On the other hand, wide fluctuations were found in the oil obtained from the young leaf and growing tips (apart from minor variations inseparable from the distillation of

comparatively small quantities of leaf on an experimental scale). The yield of oil (see fig.) increases greatly in the late spring and early summer months, which is the period of active growth: and the oil has then an exceptionally large hydrocarbon content. Despite the fact that *E. cneorifolia* oil is regarded as one from which phellandrenes are absent, a large proportion of such hydrocarbons was actually present *in the oil in the flush* period, the summer oils of young leaf readily responding to the phellandrene nitrosite test: and at this period the aldehyde content was correspondingly low.



I, *Yield of oil;* II, *terpenes* (1933—34); III, *terpenes* (1934—35).

In view of the large amounts of phellandrene present in the young leaf oils at the period of free growth, their availability as initial material for phytochemical synthesis seems to be clearly established. As the season advances the phellandrene content of the oil shows a marked decrease, and in view of the fact that β-phellandrene (I) is readily converted into 4-*iso*propyl-Δ^2-*cyclo*hexen-1-one (II) by aerial oxidation in sunlight, and also yields phellandral (III) by permanganate oxidation under controlled conditions (Wallach, *Annalen*, 1905, **340**, 1; **343**, 35), it appears valid to assume that these are formed in the eucalyptus oils by phytochemical synthesis from this hydrocarbon (see Galloway, Dewar, and Read, J., 1936, 1595).



In support of this it has been observed that the aldehyde content of some eucalyptus oils increases on storage in partly filled bottles: and the hydrocarbon fractions of the young oils at the flush period give, after treatment with air or oxygen in ultra-violet light, aldehyde values as high as 15%; and the ketone *l*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one has been isolated from such reaction products.

The phellandrenes in the oils have been systematically examined, and the work will be described in a further communication. Both *l*-α- and *l*-β-phellandrene are present, and the stereochemical biogenetic relationship *l*-β-phellandrene, *l*-phellandral, *l*-ketone is suggested. An interesting confirmation of this view is found in the case of water-fennel oil, in which the relationship *d*-β-phellandrene, *d*-phellandral, *d*-ketone has been established (see following paper).

Cuminal (IV) may be formed in the oil by dehydrogenation of phellandral, and this

would appear to be the most direct way to account for its occurrence. On the other hand, it may be derived from α-phellandrene (V) (Penfold and Simsonsen, J., **1930**, 403) or alternatively from cymene (VI).

Borgwardt and Schwenk (*J. Amer. Chem. Soc.*, 1934, **56**, 1185) have shown that on treatment with selenious acid α-phellandrene is oxidised to cuminal; and Stephens (*ibid.*, 1926, **48**, 1824) has also isolated and identified this aldehyde as an oxidation product of cymene by gaseous oxygen at 85°. About 19% of cymene is present in the young leaf oil in September, but this decreases to some 3—4% as the season advances. It has been obtained from α-phellandrene, and may be so derived in eucalyptus oils; and the fact that the cymene content of the summer oils is low, and also that their ratio of phellandral to cuminal is much lower than in the winter oils, may not be without significance in connection with the latter view of cuminal formation.

Experimental.

Distillations.—The distillations were carried out at American River, Kangaroo Island, in a direct-fired, experimental, 45-gallon still coupled to a water-cooled, copper worm-condenser. The still was charged with leaf (100 lbs.) and water (12 gallons), and the distillations continued over a period of 6—7 hours, during which the oil and approximately 7 gallons of aqueous distillate collected. The distillation was thus pushed further than is common in commercial practice, the resultant oils being consequently richer in aldehydes. The crude oils were analysed without further rectification, cineole being determined by the *o*-cresol method; alcohols, calculated as $C_{10}H_{18}O$, by difference between the ester value of the oil and the ester value after acetylation; aldehydes by the hydroxylamine method; and terpenes by difference. Typical results with growing tips and terminal branchlets are set out in Table I and shown in the figure, percentages being by weight. The leaf in all cases was cut in the same scrub area.

Table I.

Crude oils from young leaf.

Date.	Yield, %.	$d_{15.5°}^{15.5°}$.	$[\alpha]_D$.	Alcohols, %.	Aldehydes, %.	Cineole, %.	Terpenes, %.
2/1/33	1·80	0·8944	−22·10°	9·7	12·2	39·0	39·1
6/2/33	1·28	0·9138	−11·48	9·7	18·7	43·0	28·6
6/3/33	1·28	0·9227	−10·95	8·5	20·1	56·0	15·4
1/5/33	1·40	0·9232	−14·55	12·6	20·3	56·8	10·3
5/6/33	1·49	0·9248	−12·93	11·6	21·5	54·4	12·5
2/7/33	1·19	0·9237	−14·91	6·7	17·5	49·4	26·4
7/8/33	1·19	0·9217	−17·03	10·9	17·9	46·4	24·8
4/9/33	1·28	0·9213	−14·40	6·9	20·6	46·0	26·5
2/10/33	1·30	0·9109	−17·35	8·5	17·3	49·8	24·4
6/11/33	1·74	0·8906	−24·18	8·3	6·8	44·2	40·7
4/12/33	2·24	0·8795	−31·27	7·8	6·8	36·0	49·4
2/1/34	2·02	0·8927	−23·70	7·3	12·0	38·4	42·3
5/2/34	1·44	0·9183	−14·27	10·3	18·7	49·0	22·0
5/3/34	1·19	0·9206	−13·32	8·9	20·2	53·0	17·9
4/11/34	1·73	0·8961	−22·79	7·9	10·1	46·4	35·6
19/11/34	2·02	0·8940	−24·05	6·5	8·9	42·6	42·0
2/12/34	2·00	0·8926	−23·64	5·3	8·5	42·8	43·4
17/12/34	2·09	0·8876	−27·24	5·85	7·9	40·8	45·45
1/1/35	1·94	0·8910	−25·68	5·85	9·15	39·8	45·2
22/1/35	1·83	0·9031	−18·82	5·1	14·7	47·0	33·2

Apart from minor fluctuations which are to be expected in small-scale work, the results show clearly a definite increase in the yield of oil during the period of active growth. The oils at this season are characterised by a rise in the lævo-rotation and a fall in the density, which are doubtless correlated with the marked increase in the terpene content.

Side by side with the separation of oils from the growing tips, a series of similar distillations on old leaf was carried out. The results in this case showed only minor fluctuations and no marked increase in either rotation or terpene content was recorded.

To supplement the work, arrangements were made with a commercial distiller in an adjoining district for the monthly distillation of 1-ton lots of the leaf. Such leaf was naturally not subject to selection and included the young tips during the months of active growth. The rotation of the oils at this period rose from an average value of some − 5° to approximately − 9°. There was also a 5% increase in the terpene content, which rose to about 19%.

Isolation of Aldehydes.—The oils from the small-scale distillations were treated directly for the removal of carbonyl compounds by successive shaking with neutral sodium sulphite solution (5 vols.; 35% $Na_2SO_3,7H_2O$) and saturated sodium bisulphite solution (2 vols.). The neutral sulphite action is continued until phenolphthalein is no longer coloured pink, the alkali liberated being periodically neutralised by 10% sulphuric acid during treatment. This method of prior removal of the ketone is found to be much better than direct treatment with bisulphite, for in the latter case with oils rich in the ketone, considerable quantities of this are found to remain as a solid derivative in the bisulphite cake, and are subsequently isolated with the phellandral on treatment with boiling bisulphite solution in the usual purification process. The oil unabsorbed on treatment with neutral sulphite is separated and shaken for 8 hours with the bisulphite solution, the sodium sulphite extract being meanwhile decomposed with 40% sodium hydroxide, after washing with ether. The product so obtained consisted essentially of the ketone *l*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one, containing traces of phellandral. The unabsorbed oil filtered from the bisulphite cake was reserved for further treatment, and the cake itself was well washed with alcohol–chloroform–ether to remove all traces of oil. The bisulphite solution yielded a small quantity of oil on treatment with 40% sodium hydroxide solution; and this was found to consist of *l*-phellandral and some ketone. The bisulphite cake, decomposed by 5% sodium carbonate solution, gave a mixture of cuminal and *l*-phellandral, and a further small quantity of *l*-phellandral with traces of cuminal was recovered after this treatment by the addition of sodium hydroxide. The purification of cuminal and phellandral was carried out in the usual way by boiling with bisulphite solution. The ketone and the aldehydes were identified in all cases by comparison of their derivatives (semicarbazones, *p*-nitro- and 2 : 4-dinitrophenylhydrazones) with authentic specimens. Only the ketone, cuminal, and *l*-phellandral were found in the oils. The ketone appears to be present in larger amounts than cuminal or phellandral, the quantities isolated constituting 40—55% of the total estimated amount of carbonyl compounds. It is difficult to determine with any great accuracy the relative amounts of cuminal and phellandral present, but as the rotation of the mixed aldehydes obtained from the bisulphite cake rose from $-$ 6·7° in the December oil, or $-$ 11·5° in November, to some $-$ 40° in the winter oils, it is evident that cuminal preponderates in the oils of the flush period, but the proportion of phellandral increases in the winter months.

As no marked variation was found from month to month in the case of the commercial oils, the yields from November to February were mixed and treated as summer oil bulk, the remaining oils being mixed for winter oil bulk. As the cineole content was high (70—74%) and the aldehyde content low (7—9%), the separate bulks were refrigerated; and in this way upwards of one-third of the oil was removed as cineole (96% pure). The residues (6·5 gallons summer oil, $d_{15·5°}^{15·5°}$ 0·9135, $[\alpha]_D$ $-$ 7·49°, aldehydes 11·1%, cineole 59·0%; 12 gallons winter oil, $d_{15·5°}^{15·5°}$ 0·9206, $[\alpha]_D$ $-$ 6·41°, aldehydes 12·7%, cineole 61·6%) were distilled with live steam to concentrate the aldehydes in the later fractions. The aldehydes and the ketone were isolated from the fractions by the procedure already described, with the following typical results.

Fraction.	Vol., c.c.	$d_{15·5°}^{15·5°}$.	$[\alpha]_D$.	Ketone, g.	Cuminal, g.	Phellandral, g.
Winter, 6	2150	0·9426	$-$23·9°	337	130	67
,, 7	2170	0·9583	$-$33·45	422	215	65
Summer, 5	2200	0·9290	$-$15·33	315	100	4
,, 6	1420	0·9539	$-$31·68	301	221	33

In all cases the oils were carefully examined for aldehydes other than the three main carbonyl compounds, but with negative results. It will be seen that the phellandral obtained amounts to some 34% of the total cuminal + phellandral isolated in winter oil fraction 6; and 23% in fraction 7. The values in the corresponding fractions of the summer oil were 4 and 13% respectively.

Hydrocarbons and Terpenes.—The oils remaining after the isolation of the ketone and the aldehydes were shaken, after thorough washing to remove bisulphite, with 1·5 volumes of 50% resorcinol solution to remove cineole. The semi-solid cake obtained on seeding with the cineole–resorcinol compound was filtered off with suction, and repeatedly washed with the aqueous portion of the filtrate to remove adhering oil. The resorcinol treatment was repeated three or four times (depending on the amount of cineole), and the oil finally distilled under reduced pressure after thorough washing and drying. The distillates were aldehyde-free and contained no appreciable quantities of cineole or alcohols. Representative results are summarised in Table II.

The marked difference in the nature of the terpenes present in the oils during the flush

TABLE II.

Hydrocarbon and terpenes of young leaf oils.

Oil.	Fraction.	Vol., c.c.	$d^{15\cdot5°}_{15\cdot5°}$.	$[\alpha]^{20°}_D$.	Oil.	Fraction.	Vol., c.c.	$d^{15\cdot5°}_{15\cdot5°}$.	$[\alpha]^{20°}_D$.
Jan.	(1) 54°/10 mm.	30	0·852	−30·8°	Oct.	(1) 48°/8 mm.	7·5	—	−18·3°*
	(2) 52/8 mm.	60	0·854	−33·3		(2) 48/6 mm.	36	0·857	−22·8
	(3) to 60/8 mm.	55	0·861	−26·8		(3) to 52/6 mm.	39	0·865	−17·3
Feb.	(1) 45—47/5 mm.	36	0·855	− 0·75	Nov.	(1) 52/8 mm.	17	0·849	−44·2
	(2) 47/5 mm.	24	0·861	− 1·8		(2) 48/5 mm.	77	0·848	−45·6
	to 105/5 mm.	2	—	—		(3) to 58/5 mm.	70	0·853	−37·2
May	(1) 50/8 mm.	5	—	+ 1·12*	Dec.	(1) 62—65/9 mm.	45	0·846	−46·8
	(2) 52/6 mm.	30	0·867	+ 0·66		(2) 59—61/6 mm.	75	0·847	−51·4
	(3) 52/6 mm.	22	0·875	+ 0·07		(3) 62/7 mm.	45	0·848	−46·1
Sept.	(1) 65/11 mm.	9	—	+ 0·08*		(4) to 60/4 mm.	45	0·854	−33·4
	(2) 61—62/6 mm.	30	0·867	+ 0·07					
	(3) 62—63/5 mm.	22	0·885	− 0·74					

* Values are those of α_D.

period and those occurring in the other months is shown by the high *l*-rotations of the former fractions; and the high *l*-rotations of the crude oils themselves are therefore evidently due to terpenes. All the terpene fractions gave a nitrosite test, but phellandrene was found to be present in considerable amounts in those fractions distilled from the January, October, November, and December oils; and the respective crude oils themselves gave a phellandrene nitrosite test. Crude oils distilled during the other months did not give a nitrosite at laboratory temperatures, although the July, August, and September oils responded weakly to the test at − 10°. The presence of *l*-β-phellandrene is shown by oxidation of rich fractions by oxygen in ultraviolet light. The aldehyde estimation after irradiation gave a value of some 15% in cases examined, and *l*-4-*iso*propyl-Δ^2-*cyclo*hexenone was isolated by neutral sodium sulphite and identified by its derivatives. *l*-α-Phellandrene is also present, and the results of a detailed examination of the nitrosites will be communicated later.

The presence of pinene in the terpene fractions was indicated by colour development during the phellandrene test. The fractions from the May to September oils gave the most pronounced colour tests, and although attempts to form a nitrosochloride failed, a colorimetric estimation showed a pinene content of some 3%.

All attempts to prepare the characteristic limonene tetrabromide were unsuccessful, although the numerous modifications mentioned in the literature were tried.

Cymene.—Cymene has been detected in a number of the oils from the growing tips. Treatment of the terpene fractions with potassium permanganate in the cold effectively removes the terpenes. In a typical experiment, 20 c.c. of fraction 2 of September oil were shaken with 4% potassium permanganate solution in the cold, finely powdered permanganate being added as oxidation proceeded, and until a permanent pink remained for 24 hours (20 g. required). The residual oil (16 c.c.; α_D 0·04°; $d^{15\cdot5°}_{15\cdot5°}$ 0·874) was recovered by steam distillation. By admixture with pure cineole, the oil was found to contain 10·6% of cineole, by the *o*-cresol method. Oxidation by hot permanganate (Wallach, *Annalen*, 1891, **264**, 1) gave an acid which, after recrystallisation, had m. p. 158° and is evidently *p*-hydroxy*iso*propylbenzoic acid (Found, in barium salt: Ba, 27·3. Calc.: Ba, 27·7%). An estimate of the amount of cymene present in the oil follows from the isolation from 20 c.c. of terpene fraction (*d* 0·867) of 16 c.c. of cymene (*d* 0·874) containing 10·6% of cineole. The terpene content of the crude oil is a maximum of 26·5%, whence the cymene percentage in the crude oil is estimated as 26·5 × 12·5/17·34 = 19·0% by weight. This is a maximum value, as some phellandrene is removed by the resorcinol treatment, leaving the terpene fraction correspondingly richer in cymene. Cymene was similarly isolated as an inactive oil from the January, February, September, November, and December terpene fractions, and similar estimates gave the respective values of 9·5, 13·7, 19·0, 3·0, 4·0%.

We are indebted to Messrs. A. M. Bickford & Sons, Ltd., for the refrigeration and steam-distillation of the summer and winter bulks.

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299. d-*Phellandral and* d-4-iso*Propyl*-Δ^2-cyclo*hexen-1-one.*

By P. A. Berry, A. Killen Macbeth, and T. B. Swanson.

The biogenetic relationship *l*-β-phellandrene, *l*-phellandral, *l*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one, disclosed in the examination of the oil of *E. cneorifolia*, led to the examination of the oil of water fennel (*Phellandrium aquaticum*, L.), since this is a reputed source of *d*-β-phellandrene. It is now found that this oil contains *d*-phellandral (α_D + 116·22°, homogeneous), associated with *d*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one {α_D + 52·16°, homogeneous; $[\alpha]_D$ + 64·57° (alcohol; c = 5·556)}.

Examination of the nitrosite, and oxidation experiments support the previous observation that *d*-β-phellandrene is present in the oil. The occurrence in water-fennel oil of the stereoisomerides of the three related compounds found in *E. cneorifolia* appears to lend support to the biogenesis suggested.

As the examination of the seasonal variation of the oil of *E. cneorifolia* (preceding paper) disclosed the biogenetic relationship *l*-β-phellandrene, *l*-phellandral, *l*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one, it was thought of interest to examine the stereochemical character of phellandral from sources known to contain *d*-β-phellandrene. Attention was accordingly directed to water-fennel oil, obtained from the seeds of *Phellandrium aquaticum*, L., since a phellandrene identified in this oil by Pesci (*Gazzetta*, 1886, **16**, 225) was later considered by Wallach (*Annalen*, 1905, **340**, 2) to be *d*-β-phellandrene.

Water-fennel seeds were obtained for us by Messrs. Stafford Allen & Sons., Ltd., to whom we are greatly indebted, and before distillation they were compared with a specimen in the museum of the Pharmaceutical Society, and found to be undoubtedly genuine fruits, although inferior to the authentic specimen in size and colour. On distillation, the seeds yielded about 1% of oil in which the presence of *d*-β-phellandrene has now been confirmed. The mutarotation of *l*-α-phellandrene-α-nitrosite has been studied by Read and his collaborators (J., 1923, **123**, 1657; 1924, **125**, 930), and a marked change, with reversal of sign of rotation, was observed. In contrast with this, the mutarotation of *d*-β-phellandrene-α-nitrosite is slow and reversal of sign has not been noted. The specimens of the nitrosite prepared had m. p. 102—103° and $[\alpha]_D$ from − 153° to − 165·7° in chloroform, with a mutarotation to about half this value in 200 hours. Similar slow mutarotation has also been observed with *l*-β-phellandrene-α-nitrosite prepared from eucalyptus oils.

The examination of the oil has also confirmed the presence of phellandral, but although this has previously been reported as having a lævorotation of some − 36·3° (Schimmel and Co. Report, October, 1904, 88), we now find it to be the dextrorotatory aldehyde (α_D + 116·22°, homogeneous).

We have also found that the oil contains 4-*iso*propyl-Δ^2-*cyclo*hexen-1-one, and this also is dextrorotatory {$[\alpha]_D$ + 64·57° in alcohol (c = 5·556); α_D + 52·16°, homogeneous}. The biogenetic relationship between these three substances, which has been suggested to hold in the case of eucalyptus oils, would thus appear to receive confirmation from the results now recorded in the case of water-fennel oil, in which the stereoisomerides are in each case found to be present.

Experimental.

The oil was of a deep orange colour and possessed the characteristic odour of water-fennel. It had the following physical constants: $d^{15·5°}_{15·5°}$ 0·880; $n^{20°}_D$ 1·4839; $[\alpha]_D$ + 22·4°, homogeneous; which are in good agreement with those previously recorded, *viz.*, $d^{15°}$ 0·85—0·89; $n^{20°}_D$ 1·484—1·495; α_D + 12·42—19° (Gildemeister and Hoffmann, "The Essential Oils," 2nd Edn., III, 358). The aldehyde content of the oil (including the ketone) was approximately 14%.

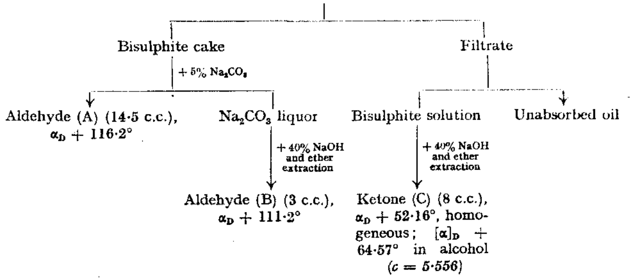
The oil (500 c.c.) was fractionated through a 70-cm. Widmer–Schenck column, and after collection of the main fractions, the residue (136 c.c.) was steam-distilled to separate aldehydes, alcohols, etc., from polymerised products, with the following results:

Fraction.	B. p.	$d^{15·5°}_{15·5°}$.	$[\alpha]_D$.
(1) 15 c.c.	21—41°/7 mm.	0·8523	+20·18°
(2) 64 c.c.	41—47/7 mm.	0·8575	+20·8
(3) 166 c.c.	44/4 mm.	0·8564	+18·85
(4) 89 c.c.	44—59/4 mm.	0·8509	+16·16
(5) 9 c.c.	59/4 mm.	—	—
Steam-distillate (94 c.c.)		0·9400	+43·62

d-β-*Phellandrene*.—The nitrosite was prepared in the usual way from fraction (2), and purified by repeated precipitation from chloroform solution by methyl alcohol. It had m. p. 96° and $[\alpha]_D$ − 159·4° in chloroform (c = 1·255). A solution of the nitrosite in chloroform showed slow mutarotation, finally attaining a value of $[\alpha]_D$ − 86° after 216 hours. The nitrosite was also prepared from fraction (3), and had m. p. 99°, $[\alpha]_D$ − 162·6° in chloroform (c = 1·255). Further purification raised the m. p. to 102—103° and $[\alpha]_D$ to − 165·7°. The chloroform solution again showed the slow mutarotation, falling to a final value of − 97·2° after 288 hours. The optical sign indicates that the substance is an α-nitrosite of *d*-phellandrene, and the slow mutarotation without reversal of sign of rotation, which is in contrast with the behaviour of the α-phellandrene-α-nitrosites, indicates that the derivative is *d*-β-phellandrene-α-nitrosite. This behaviour of the α-nitrosite of β-phellandrene has been confirmed by the examination of the derivatives of *l*-β-phellandrene from *E. cneorifolia* and other sources.

The identity of the terpene as β-phellandrene was also shown by oxidation experiments. The regulated oxidation with 1% permanganate (Wallach, *Annalen*, 1905, **340**, 1) led to the isolation of the glycol, which, when distilled with 10% sulphuric acid, gave an aldehyde in the distillate. This on extraction gave a 2 : 4-dinitrophenylhydrazone, m. p. 203—204° after recrystallisation from chloroform–alcohol, which showed no depression on admixture with the corresponding derivative of *d*-phellandral (below). The ærial oxidation of fraction (4) was also examined. The oil (80 c.c.) was placed in a quartz flask with water (50 c.c.), and oxygen bubbled through at a rate sufficient to mix the two liquids during irradiation by light from a mercury lamp for 6 hours. The aldehyde content (calculated as $C_9H_{14}O$) rose from 3·3% to approximately 14·1%. Extraction with neutral sodium sulphite led to the isolation of the ketone *d*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one, α_D + 46·7° in alcohol (c = 20), which gave a *p*-nitrophenylhydrazone crystallising from methyl alcohol as glistening yellow needles, m. p. 167°, undepressed on admixture with the same derivative from another specimen of the *d*-ketone (below).

Isolation of the Aldehyde and Ketone.—The steam-distillate (86 c.c.) was shaken for 8 hours with sodium bisulphite (175 c.c., 35% solution), and the various aldehyde fractions separated as shown schematically below :



Identification of d-4-iso*Propyl*-Δ^2-cyclo*hexen*-1-*one*.—The oil (C), separated on treatment of the bisulphite solution, was identified as this ketone by the preparation of the following derivatives : p-*nitrophenylhydrazone*, glistening yellow needles from methyl alcohol, m. p. 167·5° (Found : N, 15·3. $C_{15}H_{19}O_2N_3$ requires N, 15·4%) ; 2 : 4-*dinitrophenylhydrazone*, red needles from alcohol, m. p. 136° (Found : N, 17·3, 17·4. $C_{15}H_{18}O_4N_4$ requires N, 17·6%). Part of the ketone (2·5 g.) in alcohol (25 c.c.) was catalytically reduced in the presence of palladised charcoal (hydrogen absorbed at N.T.P., 416 c.c. ; theory, 396 c.c.), and the reduced ketone identified as 4-*iso*propyl*cyclo*hexanone by preparation of the semicarbazone, m. p. 186°, and the *p*-nitrophenylhydrazone, m. p. 124°, which gave no depression on admixture with the respective derivatives prepared from the reduction product of the *l*-ketone from eucalyptus oils.

Identification of d-*Phellandral*.—The preparation of derivatives showed that aldehydes (A) and (B) were the same, and they were identified as *d*-phellandral by the following compounds : semicarbazone, white leaflets, m. p. 200° ; *p*-nitrophenylhydrazone, yellow needles, m.p. 174—175° ; 2 : 4-*dinitrophenylhydrazone*, deep orange micro-crystals, m. p. 204° (Found : N, 17·0, 17·1. $C_{16}H_{20}O_4N_4$ requires N, 16·9%). The structural identity of the aldehyde with the *l*-

phellandral from eucalyptus oils was shown by oxidation by 4% permanganate solution. The oxidation product, recovered by extraction with ether after removal of the manganese dioxide and concentration and acidification of the filtrate, had, after recrystallisation from water and from chloroform–light petroleum, m. p. 71°, undepressed on admixture with the oxidation product (m. p. 70—72°) similarly prepared from *l*-phellandral from *E. cneorifolia* oil.

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300. *The αα'-Dicyclohexylsuccinic Acids.*

By (MISS) A. R. MURRAY and T. W. J. TAYLOR.

The preparation of simple monobasic and dibasic acids containing two substituents such as the cyclohexyl group cannot be achieved by the simple condensation reactions which can be used in other cases. These acids are, however, possible starting materials for investigating interesting problems of isomerism and isomeric change. Hence an electrolytic method of preparing αα'-dicyclohexylsuccinic acid has been attempted and has proved successful. The two possible stereoisomeric forms of that acid have been obtained, and their properties show that the cyclohexyl group has a very large steric effect; for example, the anhydride which one of them forms is only attacked slowly by boiling alcoholic potash.

αα'-DI*cyclo*HEXYLSUCCINIC acid, αβ-di*cyclo*hexylpropionic acid, and their derivatives might serve as useful intermediate substances for the preparation of compounds which could be used for studying the many possibilities of isomerism and geometrical isomerism of unsaturated substances containing two alicyclic rings, a problem about which little is known, and which is becoming of increasing interest. Attempts to obtain either of these acids by ordinary condensation reactions from *cyclo*hexylmethyl bromide or *cyclo*hexyl bromide were unsuccessful, and consequently the experiments described here were undertaken to see whether a general method of preparing symmetrically disubstituted dibasic acids with alicyclic substituents could be found in the electrolysis of the salts of the half esters of compounds of the type of *cyclo*hexylmalonic acid. Conditions were eventually found under which potassium ethyl *cyclo*hexylmalonate can be converted into a mixture of the racemic and the meso-form of ethyl αα'-di*cyclo*hexylsuccinate, but the yield is not good, being only 17% under the most favourable conditions.

The electrolytic method of preparing succinic acids was discovered by Crum Brown and Walker (*Annalen*, 1891, **261**, 107), and was applied by them to the preparation of dimethyl-, diethyl-, tetramethyl- and tetraethyl-succinic acids. They showed that the yield is improved by working at high salt concentration and with an anode of small area. Since then the conditions that determine the formation of succinic acid from potassium ethyl malonate have been studied by Robertson (J., 1925, **127**, 2057), who found that with an anode of gold or platinised platinum no succinic ester is formed, but that grey or smooth platinum can be used. The mechanism of the synthesis has been discussed in detail by Fichter and his co-workers (*Helv. Chim. Acta*, 1935, **18**, 445, 704). The cell used in this work is described in the experimental section. Its main features were that: (1) the anode, a small loop of platinum wire, could be rotated rapidly to ensure efficient cooling in the region of the anode; (2) a streaming mercury cathode was used in order to remove from the cell the liberated potassium, and to avoid the accumulation of hydroxyl ions in the solution. Without the latter precaution the current is carried mainly by the hydroxyl ions and the yield of the desired ester falls; such a cathode makes it unnecessary to introduce a diaphragm (Meyer and Hofer, *Ber.*, 1895, **28**, 2427), which increases the total resistance and thus lengthens the time of electrolysis. A stationary mercury cathode has been used for the same purpose by Fairweather (*Proc. Roy. Soc. Edin.*, 1924, **45**, 31). Repetition of Crum Brown's synthesis of adipic ester from potassium ethyl succinate with our cell gave a yield of 50% of theory, as compared with the 35% yield which he obtained. Fichter and Heer (*Helv. Chim. Acta*, 1935, **18**, 704) obtained 60%, but gave no details of their procedure.

Electrolysis of potassium ethyl *cyclo*hexylmalonate at first gave only an oil which consisted essentially of ethyl hydrogen *cyclo*hexylmalonate, set free from its potassium salt, most probably by acids formed in anodic oxidation. In very concentrated solution, however, the ethyl esters of the two stereoisomeric αα'-di*cyclo*hexylsuccinic acids were formed in small amounts. The two esters differ widely in m. p., and can be separated because the higher-melting ester is almost insoluble in cold alcohol. They are both very difficult to hydrolyse and are only slowly attacked by boiling alcoholic potash. In this they resemble the tetramethyl- and tetraethyl-succinic esters (Crum Brown and Walker, *Annalen*, 1893, **274**, 41), and differ from the dimethyl-, diethyl- and diphenyl-succinic esters, all of which can be conveniently hydrolysed with alcoholic potash. The steric effect of one *cyclo*hexyl group seems to be much greater than that of a simple alkyl or aryl group. The most convenient reagent for the hydrolysis of both esters was found to be a mixture of sulphuric acid, acetic acid, and water at 140°. Under these conditions both esters give the same products, an *acid* of high m. p. and a very stable *anhydride*; the latter was shown to be related to a lower-melting *acid*, so both stereoisomeric acids are obtained from either ester, and interconversion of the isomers takes place under the vigorous conditions needed for the hydrolysis. The product of the slow alkaline hydrolysis is, as would be expected, also a mixture of the two acids, which can be separated by means of their barium salts. The higher-melting ester was, however, shown to be that of the higher-melting acid by esterification of that acid through its silver salt. The anhydride is only slowly attacked by aqueous or alcoholic potash, and the product is again a mixture of the two acids. It reacts readily, however, with anilinomagnesium iodide to give an anilic acid. The stability of the anhydride resembles that of tetraethyl- and tetraphenyl-succinic anhydrides (Walker and Walker, J., 1905, **87**, 961; Crichton, J., 1906, **89**, 929), and again shows the large steric effect of a *cyclo*hexyl group. Which of the two acids is the racemic and which the *meso*-form can only be settled by the optical resolution of one, but the consistent analogies in anhydride formation, solubilities of the barium salts, and the m. p.'s of the acids and their esters with the corresponding properties of the two dimethyl- (Werner and Basyrin, *Ber.*, 1913, **46**, 3229), diethyl- (Wren and Haller, this vol., p. 230), and diphenyl-succinic acids (Wren and Still, J., 1915, **107**, 444), in all of which cases one acid has been resolved, make it very probable that the lower-melting acid is the racemic form. Attempts to convert either acid into di*cyclo*hexylethylene by electrolysis of their salts have so far proved unsuccessful.

EXPERIMENTAL.

The following condensations were attempted under a variety of conditions, but in no case could the desired products be obtained: *cyclo*hexylmethyl bromide with the sodium derivatives of *cyclo*hexyl-malonic or -cyanoacetic ester or *cyclo*hexenylmalonic ester; *cyclo*hexyl bromide with the disodium derivative of ethanetetracarboxylic ester; *cyclo*hexylchloromalonic ester with sodio*cyclo*hexylmalonic ester; the action of iodine on sodio*cyclo*hexylmalonic ester.

Ethyl *cyclo*hexylmalonate was prepared by the reduction of the *cyclo*hexenyl ester (Kon and Speight, J., 1926, 2730) on palladised strontium carbonate, from *cyclo*hexylcyanoacetic ester (Vogel, J., 1928, 2023), or, most conveniently, from *cyclo*hexyl bromide and malonic ester (Hiers and Adams, *J. Amer. Chem. Soc.*, 1926, **48**, 2385). The yield obtained by the last method was 40% of theory, and attempts to improve it by using benzene as solvent or potassium carbonate in place of sodium were unsuccessful; the yield is seriously diminished if the reaction mixture is not stirred continuously.

Potassium ethyl *cyclo*hexylmalonate is best obtained by isolating the half ester. Ethyl *cyclo*hexylmalonate (143 g.) in 1200 c.c. of absolute alcohol was treated with potassium hydroxide (16 g.) in 10 c.c. of water and 400 c.c. of alcohol. When the alkaline reaction had disappeared (2—3 days), most of the alcohol was removed on the water-bath, and the residue treated with 80 c.c. of water and thoroughly extracted with ether to remove unchanged ester. The dissolved ether was removed in a stream of air, and the solution cooled in ice and acidified with phosphoric acid; ethyl hydrogen *cyclo*hexylmalonate separated as an oil, some samples of which solidified to colourless crystals, m. p. 44—45°. The compound boils at 163°/15 mm. with partial decomposition to ethyl *cyclo*hexylacetate. In most experiments the oil was neutralised with concentrated aqueous potassium hydroxide, and the solution diluted to the desired extent.

Two cells were used for the electrolysis, one holding 90 c.c. and the other 15 c.c.; the general design of both is shown in the figure. Mercury flows down the narrow side tube from a tap-funnel, wells up in the cup at the bottom of the cell, and drains away through the bottom tap; electrical connection is made to this mercury by a wire sealed through the side tube. The anode is a loop of platinum wire of surface area 0·35 sq. cm., and is rotated rapidly; the cell is surrounded by a large inverted bell-jar containing ice and water frequently renewed. The current was taken from a 100-volt D.C. supply, and regulated by a sliding resistance. In a series of trials with different concentrations of electrolyte and different current strengths, it was found that if the volume of electrolyte exceeded 28 c.c. for each 10 g. of the salt, the product was an oil which consisted of ethyl hydrogen *cyclo*hexylmalonate. When the oil was distilled, it partly decomposed and gave two fractions: (i) b. p. 100—105°/15 mm., shown to be ethyl *cyclo*hexylacetate by hydrolysis and conversion of the acid into its amide; (ii) b. p. 163—165°/15 mm., which was ethyl hydrogen *cyclo*hexylmalonate, as shown by hydrolysis and the mixed m. p. of the acid so obtained with an authentic sample of *cyclo*hexylmalonic acid. With more concentrated solutions, a solid separated during the electrolysis, and this proved to contain the esters of the two desired di*cyclo*hexylsuccinic acids. Alteration of current strength showed that if it exceeded 5 amps., complete anodic oxidation took place and no organic product could be isolated. The best current was found to be 1 amp.; if it were smaller, the time of electrolysis became inconveniently long.

After many trials the procedure for obtaining the best yields of the desired esters seemed to be the following. 90 C.c. of a solution containing 61 g. of potassium ethyl *cyclo*hexylmalonate were electrolysed with a current of 1 amp.; after 4 hours the current was stopped, the solid formed removed, and the solution extracted with ether. The aqueous layer was acidified with phosphoric acid, 21 g. of ethyl hydrogen *cyclo*hexylmalonate separating. This was converted into the potassium salt, and electrolysed at the same concentration for a further 3 hours. In this way electrolysis of a dilute solution was avoided. The resulting solution was extracted with ether, and then on acidification gave 12 g. of the half ester. Thus 46·8 g. of the potassium salt have disappeared; the combined yield of the two di*cyclo*hexylsuccinic esters was 5·3 g., so that this, the best yield obtained, is 17% of the theoretical.

The ether was removed from the extracts, the residual oil combined with the solid which had been formed, and the whole treated with a little cold alcohol. The solid which separated on standing was recrystallised from light petroleum and formed colourless needles, m. p. 120° (3 g.), of (?)meso-*ethyl* di*cyclohexylsuccinate* (Found: C, 70·8; H, 10·2. $C_{20}H_{34}O_4$ requires C, 71·0; H, 10·1%). The alcoholic filtrate was distilled under reduced pressure and gave 9·6 g. of a mixture of ethyl hydrogen *cyclo*hexylmalonate and ethyl *cyclo*hexylacetate (b. p. 100—160°/15 mm.) and 2·3 g. of a viscous oil (b. p. 203—210°/15 mm.), which solidified on standing; it was recrystallised from aqueous acetic acid and formed odourless crystals, m. p. 60°, soluble in cold alcohol. This is (?) r-*ethyl* di*cyclohexylsuccinate* (Found: C, 71·2; H, 10·1%). Attempts to improve the yield by adding a little alcohol to the solution in the cell or by adding a little mercuric cyanide were completely unsuccessful. Mercuric cyanide, which acts as an inhibitor for the decomposition of hydrogen peroxide on the surface of the electrodes, was found by Glasstone and Hickling (J., 1934, 1878) to improve the yield of ethane in the electrolysis of acetates, but it has a definitely harmful effect in the present case.

Hydrolysis of the Esters.—The higher-melting ester is not completely hydrolysed by refluxing with excess of alcoholic potash for 10 hours. The product obtained (m. p. 140—145°), is a mixture of the two stereoisomeric acids, which cannot be separated by crystallisation from aqueous alcohol or by crystallisation of the potassium salts from water. Addition of barium chloride to a solution of the mixed potassium salts gave a white precipitate of a sparingly soluble barium salt; this yielded an acid which could be crystallised from aqueous acetic acid and melted at 147° on rapid heating. This is (?)r-*di*cyclo*hexylsuccinic acid* (Found: C, 68·0; H, 9·2. $C_{16}H_{26}O_4$ requires C, 68·1; H, 9·2%). It is insoluble in light petroleum and benzene, and easily soluble in cold alcohol. Even below its m. p. the acid loses water to give an *anhydride*, m. p. 62·5°, recrystallised from aqueous acetic acid or light petroleum (Found: C, 72·7, 73·2; H, 9·1, 9·1. $C_{16}H_{24}O_3$ requires C, 72·7; H, 9·1%). Acidification of the filtrate from the sparingly soluble barium salt gave the higher-melting acid, (?)meso-*di*cyclo*hexylsuccinic acid*, which, recrystallised from aqueous acetic acid, melted at 225° [Found (micro), after drying in high vacuum: C, 68·6; H, 9·2%]. The acid forms a *dihydrate* when crystallised from aqueous solvents (Found: loss of weight on drying, 11·0. $C_{16}H_{26}O_4,2H_2O$ requires $2H_2O$, 11·3%).

and is insoluble in cold alcohol. Its silver salt, heated with ethyl iodide, gave an ester, m. p. 120°, identical (mixed m. p.) with the higher-melting ester formed in the electrolysis.

The ester of higher m. p. is unattacked by boiling with 30% sulphuric acid, but can be hydrolysed by heating for 2 hours with a mixture of sulphuric and acetic acids and water (46 : 26 : 18, by vol.). The product consists of the higher-melting acid and the anhydride of the lower-melting acid; the two can be separated with aqueous sodium carbonate. When the proportion of sulphuric acid was increased, and heating continued for 6 hours at 165°, the product was a mixture of the anhydride and the lower-melting acid (mixed m. p. with acid from less soluble barium salt, 146°). Acid hydrolysis of the lower-melting ester at 140° gave only a small quantity of the higher-melting acid, and a 67% yield of the anhydride.

When heated with resorcinol and sulphuric acid, (?)*r*-di*cyclo*hexylsuccinic anhydride gives a compound which is fluorescent in alkaline solution. The anhydride reacts with anilinomagnesium iodide (Bodroux, *Compt. rend.*, 1904, **138**, 1427; cf. Hardy, J., 1936, 398) in warm ether to give the *half-anilide* of di*cyclo*hexylsuccinic acid which was recrystallised from alcohol, m. p. 225° (Found: C, 74·3; H, 8·7; N, 4·0. $C_{22}H_{31}O_3N$ requires C, 74·0; H, 8·7; N, 3·9%). The anhydride is insoluble in aqueous caustic alkalis, and is slowly hydrolysed by boiling alcoholic potash to give a mixture of the two acids, similar to that formed in the alkaline hydrolysis of the esters.

THE DYSON PERRINS LABORATORY, OXFORD. [*Received, June 22nd*, 1937.]

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301. *The Influence of Solvents and Other Factors on the Rotation of Optically Active Compounds. Part XXXVI. Asymmetric Solvent Action.*

By T. S. PATTERSON and ALEXANDER H. LAMBERTON.

In the present work an attempt has been made to ascertain whether the volume of *iso*butyl *d*-tartrate in *l*-menthyl acetate is different from that of *iso*butyl *l*-tartrate, using solutions of about 5% concentration. Two sets of determinations were carried out by different observers, using different material and at an interval of 31 years. Both sets showed a slight and very similar difference, several times as great as the estimated probable error.

In the second series of observations the volume of the same samples of the tartrates was similarly determined in the symmetrical solvent nitrobenzene, and, unexpectedly, a difference almost similar in amount to that obtained in the asymmetrical solvent was found. The experiments were thus a little inconclusive, but it seems to be established with some definiteness that the volume of these two antimers, within the limits of experimental error, is the same in the asymmetrical as in the symmetrical solvent.

AMONGST other problems of optical activity, a possible difference in the solvent influence of the dextro- as compared with the lævo-form of one active compound upon some other active compound has received attention. Thus, van 't Hoff (" Lagerung der Atome im Raume," 1894, p. 30; 1908, p. 8) surmised that, in an active solvent, the solubility of the dextro-form of another active substance might differ from that of the lævo-variety; and *a priori* considerations are, apparently, so much in favour of this being the case that Holleman (" Organic Chemistry," Engl. Edn., 1905, p. 240) says dogmatically, " the solubility of optical isomers . . . must be different in an optically active solvent. . . . It is true that optically active isomers have a perfectly similar structure, but in relation to an optically active solvent their configurations are different so that they behave towards it like ordinary isomers, and must, therefore, have different solubilities." The experimental work on the subject hardly justified this confidence, but it is not discussed here, since a good account of it up to 1907 was given by Ranken and Taylor (*Proc. Roy. Soc. Edin.*, 1906—7, **27**, 172). Since then Campbell (J., 1929, 1111) has reported work having some bearing on the subject [see also Ebert and Kortum (*Ber.*, 1931, **64**, 342), Schröer (*Ber.*, 1932, **65**, 966), and McKenzie and Christie (*Biochem. Z.*, 1935, **277**, 122)].

Now, if solution is, as often supposed, a sort of chemical combination between solvent and solute, the behaviour suggested by van 't Hoff and Holleman might reasonably be expected. There does not, however, appear to be much greater reason in favour of this view of solution than there is for its being purely physical, as is usually postulated for the mixing of two gases like nitrogen and oxygen; and if solution be of the latter type, there does not seem to be any reason to expect that, *e.g.*, *d*- should differ from *l*-ethyl tartrate in its solvent action upon some other active compound such as *l*-menthol. If the constituent atoms of ethyl *d*-tartrate are collected together in the molecule in such a way that only a resultant external field acts on the molecules of *l*-menthol, this external field need not differ from that of ethyl *l*-tartrate, even towards an asymmetric compound.

Since the rotation of a mixture of an active with an inactive compound is not, in general, the sum of the rotations of the constituents, it is even less likely that the rotation of a mixture of two active compounds should be the sum of the rotations separately. But although it is possible to measure the sum of two such rotations, it is impossible, at present, to determine the amount which each constituent contributes to the total rotation; in any equations which can be established, there are always too many unknowns to make a solution possible.

The present investigation was, therefore, directed more particularly to the question of volume change, which, although perhaps not capable of affording a conclusive answer, might yield at least some useful information. The problem then becomes that of finding whether the densities of similar mixtures of an active compound, first with the *d*- and then with the *l*-form of some other active substance, are the same or not.

The substances chosen as solutes were *d*- and *l*-*iso*butyl tartrate, because, since they crystallise well, they are more easily purified, and obtained in closely analogous condition, than liquids like ethyl *d*- or *l*-tartrate, which, from the point of view of rotation, would have been preferable. As solvent, menthyl acetate was chosen, since it should be obtained easily in pure condition. Solutions of *iso*butyl *d*- and *l*-tartrate, severally, of as nearly as possible the same composition, were made up and examined in regard to both density and rotation. The whole experiment was then duplicated, to allow of an estimate of the experimental error.

The samples of *iso*butyl *d*- and *l*-tartrate were those already described (J., 1913, **103**, 174; the density at 108·6°, quoted on p. 175, should be 1·0007, not 1·007). The rotation of the *d*-ester for various colours of light and at different temperatures is given in J., 1916, **109**, 1161. The two esters melted at 73—74°, and seemed identical in rotation.

Solutions of the two esters in carefully purified *l*-menthyl acetate were examined. To the density determinations special care was directed. The weighings were made with a good Bunge balance and with adjusted weights. Several determinations in all cases were made close to 20°, a thermometer graduated clearly to 0·05° being used; and then—by calculation, not plotting on a diagram—the density at 20° was estimated. Table I summarises the data obtained, p being the proportion of the tartrate and q that of menthyl acetate.

TABLE I.

Soln.	p, %.	q, %.	$d_{4°}^{20°}$.	α_D (70 mm.).	Soln.	p, %.	q, %.	$d_{4°}^{20°}$.	α_D (70 mm.).
		d-*Tartrate*.					l-*Tartrate*.		
I	5·4632	94·5368	0·932495	−48·00°	III	5·46761	94·53239	0·932506	−49·73°
II	5·46759	94·53241	0·932501	−48·05	IV	5·324115	94·675885	0·932316	−49·84

$d_{4°}^{20°}$ of *l*-menthyl acetate = 0·925159.

Considering, in the first place, the rotation data, it appears that the values for the rotations of solutions I and II and of solutions III and IV, respectively, agree very closely; and, since the concentrations of solutions II and III are almost identical, these two solutions —the one of *d*- and the other of *l*-ester—may be used for direct comparison. If, from the values quoted, specific rotations are calculated as if the whole of the rotation were due to the *iso*butyl tartrate (*i.e.*, by inserting the value of p in the formula $[\alpha]_D^t = \alpha/l\,p\,d$)

and the menthyl acetate were inactive, the values, $-$ 1346·6° and $-$ 1393·6°, for the specific rotations of II and III, respectively, are found.

Then if α is the rotation of *iso*butyl *d*-tartrate, and $-\beta$ that of *l*-menthyl acetate we may write

$$\text{for II} \quad \alpha - \beta = -1346{\cdot}6^\circ$$
$$\text{and for III} \quad -\alpha - \beta = -1393{\cdot}6^\circ$$

whence $[\alpha]_D^{20^\circ} = \pm 23{\cdot}5^\circ$ (Patterson, J., 1913, **103**, 174, by extrapolation for the homogeneous ester gives $[\alpha]_D^{20^\circ} = \pm 17{\cdot}75^\circ$).

On the other hand, if specific rotation is similarly calculated with reference to the proportion, q, of menthyl acetate contained in the solution, we obtain as the specific rotation of II, $-$ 77·89°, and of III, $-$ 80·61°. Then, as before,

$$\text{II} \quad \alpha - \beta = -77{\cdot}89^\circ$$
$$\text{III} \quad -\alpha - \beta = -80{\cdot}61^\circ$$

whence $-\beta = -79{\cdot}25^\circ$. The specific rotation of the homogeneous menthyl acetate was, in fact, $-$ 79·45°.

It thus appears that menthyl acetate as a solvent somewhat increases (numerically) the specific rotation of *iso*butyl tartrate, and that, conversely, the tartrate slightly diminishes that of the acetate, but since there is much more menthyl acetate than *iso*butyl tartrate in the solutions, it is to be expected that the former would be less affected.

It must be observed, however, that, although this gives us some indication of the mutual solvent effect of these two active compounds, the method of calculation completely eliminates the influence which we particularly wish to detect, since it tacitly assumes that the *d*- and the *l*-form of *iso*butyl tartrate have an identical effect on the rotation of menthyl acetate, and conversely.

Turning now to the density determinations, it is found that if the four values of Table I are plotted on a diagram against proportion of *iso*butyl tartrate (p), on a scale in which 1 mm. represents 10^{-6} unit for both p and $d_{4^\circ}^{20^\circ}$, the values of $d_{4^\circ}^{20^\circ}$ for solutions I, II, and IV lie on a straight line, from which that for III only diverges by 5×10^{-6} unit. The data, therefore, possess a considerable degree of accuracy.

In order to institute, in regard to density or volume changes, a comparison similar to that of specific rotations, these values may be calculated to represent the molecular solution volume (M.S.V.) of one of the constituents, but this involves the assumption that all the volume change, if any, is suffered by that constituent. It affords, nevertheless, a suitable standard of comparison, practically unaffected by small differences in concentration. Thus for *iso*butyl tartrate,

$$\text{M.S.V.} = M[100/d_2 - (100 - p)/d_1]/p$$

where M = molecular weight (262), and d_2 and d_1 are the densities ($d_{4^\circ}^{20^\circ}$) of the solution and the pure solvent respectively. Applying this, we have :

d-Solution No.	M.S.V., ml.	*l*-Solution No.	M.S.V., ml.
I	242·424	III	242·372
II	242·416	IV	242·360
	Mean 242·420		Mean 242·366

There appears therefore to be a difference of 0·054 ml. in the mean value of the M.S.V. of these esters. It is thus only small (about 1 part in 4500), but appears to be definitely greater than the difference between the M.S.V. values for solutions III and IV or I and II, respectively, and therefore to be greater than the experimental error.

The foregoing series of experiments was carried out by one of us 31 years ago; but, although the result seemed to be positive, it was considered desirable, for confirmation, to repeat the work *ab initio*. It has only now become possible to carry out a second set of experiments in which somewhat greater precautions were taken than before. The same pyknometer was used—it had altered slightly in volume—but a different set of weights, which were carefully calibrated. The thermometer was that previously used. The weighings were reduced to *vacuo*, with due allowance for all changes in air pressure and temperature.

Fresh samples of the *iso*butyl tartrates were prepared, and purified with special care; the same applying to the menthyl acetate. The m. p.'s of the *iso*butyl esters were taken simultaneously, and found to be identical. The setting points were 72·7°, as obtained by means of another thermometer calibrated from the setting point of pure naphthalene, 80·1° (Francis and Collins, J., 1936, 138). Several mixtures, containing about 5·4% of the tartaric esters were made, the density determined over the temperature range 19·7—20·3°, and the density at 20° then calculated by interpolation. The results are summarised in Table II.

TABLE II.

Solutions in l-*menthyl acetate* ($d_{4^\circ}^{20^\circ}$ = 0·925337).

*iso*Butyl *d*-tartrate.				*iso*Butyl *l*-tartrate.			
No.	*p*, %.	$d_{4^\circ}^{20^\circ}$.	M.S.V., ml.	No.	*p*, %.	$d_{4^\circ}^{20^\circ}$.	M.S.V., ml.
V	4·9944	0·931982	242·719	IX	5·3989	0·932528	242·699
VI	5·4009	0·932532	242·691	X	5·3990	0·932530	242·688
VII	5·3979	0·932519	242·742	XI	5·4005	0·932533	242·683
VIII	5·3998	0·932522	242·732				
XII	5·3980	0·932519	242·743				
		Mean	242·725			Mean	242·690

This second series of experiments, although completely independent of the first as regards materials, and carried out many years later by a different observer, thus yields a very closely similar result. The slightly different values for M.S.V. may be due primarily to the fact that the two samples of menthyl acetate used were slightly different in density. This, of course, is in the nature of a constant error, affecting all the results in the series of experiments in a similar fashion. The relative values of M.S.V. in both series of experiments are, however, much the same. The solution volume of *iso*butyl *d*-tartrate in *l*-menthyl acetate appears to be slightly greater than that of its antipode, and by almost the same amount as before, 0·035 ml. These, it should be noticed, are not selected results, all that were carried out being reported, and since they are almost completely consistent, they can hardly be due to mere chance. Of the values obtained, No. VI and, to a less extent No. V, are the only ones which seem slightly out of agreement. If the mean value of VII, VIII, and XII, 242·738 m*l*., be taken for the *d*-ester, the difference between the M.S.V. of the *d*- and the *l*-ester becomes 242·738 — 242·690 = 0·048 ml., which is very close to that (0·054 ml.) found in the first set of experiments. It must, however, be admitted that the difference is very small; and, although we consider it to fall definitely outside the experimental error—which we reckon at about ± 0·015 ml.—it is not much beyond it (see p. 1458).

It would be very difficult to repeat these experiments to secure convincingly greater accuracy; but it occurred to us that something in the nature of an ***experimentum crucis*** might be achieved, by determining the density of the same samples of *iso*butyl *d*- and *l*-tartrates in a symmetrical solvent; if, then, the M.S.V.'s for the *d*- and the *l*-ester were identical within our limit of experimental error, the differences which we had found in the asymmetrical solvent could, although small, be regarded as real.

In the first place, we attempted to use *iso*butyl alcohol. The results, however, were quite irregular, and obviously much less accurate—as shown by plotting on squared paper—than the others. This would seem most probably to be due to the comparatively easy volatility of the solvent; and the difficulty which this causes is an illuminating side-light on the delicacy with which these experiments have to be made.

We therefore abandoned *iso*butyl alcohol in favour of nitrobenzene, which has a b. p. not much different from that of menthyl acetate. The same samples of *iso*butyl *d*- and *l*-tartrates were used, and the results were as shown in Table III.

TABLE III.

Solutions in nitrobenzene ($d_{4^\circ}^{20^\circ}$ = 1·203298).

*iso*Butyl *d*-tartrate.				*iso*Butyl *l*-tartrate.			
No.	*p*, %.	$d_{4^\circ}^{20^\circ}$.	M.S.V., ml.	No.	*p*, %.	$d_{4^\circ}^{20^\circ}$.	M.S.V., ml.
XIII	5 3656	1·195703	243·511	XIV	5·3654	1·195722	243·447
XVI	5·3641	1·195711	243·491	XV	5·3669	1·195719	243·450
		Mean	243·501			Mean	243·449

It may be noticed, first, that the M.S.V. in nitrobenzene of each isomeride of *iso*butyl tartrate is greater than in menthyl acetate by almost the same amount, 0·776 ml. for the *d*-compound, and 0·759 ml. for the *l*-compound—a very close agreement. Secondly, there is the consequent, but unexpected, result that the M.S.V. in nitrobenzene—a symmetrical solvent—of *iso*butyl *d*-tartrate is greater than that of the *l*-tartrate by 0·052 ml., very nearly the same as the difference, 0·035 ml., observed in the asymmetric solvent, menthyl acetate, using the mean value of V, VI, VII, VIII, and XII, and still nearer to that, 0·048 ml., obtained if the mean of VII, VIII, and XII is taken.

These experiments are thus, unfortunately, still a little indecisive. There appears to be a difference in the solution volume of *iso*butyl *d*- and *l*-tartrate in menthyl acetate, which is beyond the experimental error, but since there is a similar difference for the M.S.V. of these two active compounds in the symmetrical solvent, nitrobenzene, there would seem to be no preferential action of the asymmetric solvent with regard to one or other of the asymmetric solutes. The fact that the same difference in M.S.V. was found in menthyl acetate and in nitrobenzene is not easy to account for; it would certainly be remarkable, after the purification to which the material we used was subjected, if these differences should be due to a different degree of purity too small to show in the m. p.'s or rotatory powers of the two active esters used. But it would perhaps be even more remarkable if there should be a difference between a *d*- and a *l*-isomeride towards a symmetrical solvent.

In connection with the foregoing work we also compared the densities of *iso*butyl *d*-tartrate and *iso*butyl racemate, in the homogeneous condition, above their m. p.'s. The data (p. 1459), when graphed, lie, as nearly as can be judged, on one and the same curve; any variations being irregularly distributed about the curve. It will easily be understood that determinations of density at higher temperatures—and especially when the substance solidifies but little below these temperatures—are much more difficult and less accurate than are those for the esters in menthyl acetate at room temperature; but we think, from our results, that there is no reason to suppose that the density of *iso*butyl racemate in the liquid state is different from that of *iso*butyl *d*-tartrate under like conditions. Campbell's values lie very far off our graph. He quotes (*loc. cit.*, p. 1116) 1·0213 for the density of *iso*butyl *d*-tartrate at 80°, and 1·0160 for the racemate, whereas from our graph the value 1·02736 is obtained for both. In contrast, the value quoted by one of us in 1913 (J., **103**, 261) for the *d*-ester at 98·2° was 1·0107, whilst from our present results the value 1·0105 is obtained—a difference of only 2×10^{-4} unit. The differences between Campbell's data and ours are, respectively, 30 and 56 times as great. Campbell, however (*loc. cit.*), gives 58° as the m. p. of his racemate, whilst we found 63°; and 70° for his *iso*butyl *d*-tartrate, whilst our m. p. was 72·7°. Although Campbell's values for the density of his *iso*butyl tartrate and *iso*butyl racemate are less than ours at 80°, they are greater at 100°, so that his density–temperature coefficient is different also, but since he was working with substances several degrees too low in m. p., his conclusions can hardly be accepted with any confidence.

EXPERIMENTAL.

*First Set of Observations.**—The menthyl acetate used boiled at 116°/22 mm. (bath 182°), and gave the following data on polarimetric examination:

t.	*d*.	α_D (40 mm.).	$[\alpha]_D$.	$[M]_D$.	*t*.	*d*.	α_D (40 mm.).	$[\alpha]_D$.	$[M]_D$.
13°	0·9307	−29·637°	−79·61°	−157·6°	53°	0·8981	28·408°	79·08°	−156·6°
16·6	0·9278	29·488	79·46	157·3	67·1	0·8865	27·963	78·86	156·1
*20	*0·9252	*29·40	*79·45	*157·3	98·1	0·8612	27·071	78·59	155·6
36·9	0·9115	28·848	79·12	156·7					

In addition to those quoted above, two other density determinations were made, in a larger pyknometer of capacity about 31 c.c. The weighings from which these were calculated were all made at very nearly the same temperature and pressure, so correction for air displacement was not necessary. From these two, by calculation, the value at 20° was found:

t	*17·08°*	* *20°*	*21·05°*
d	0·927571	0·925159	0·924292

* Here and throughout, interpolated values are marked with an asterisk.

iso*Butyl* d-*tartrate in* l-*menthyl acetate.*

Solution I; p = 5·4632.

t.	d.	$\alpha_D^{t°}$ (100 mm.).
17·65°	0·9344	−68·73°
*20	0·9325	−68·57
39·7	0·9160	−67·14
57	0·9015	−65·88

t	19·55°	*20°	20·64°	25·5°	47·8°
d	0·932855	*0·932496	0·931983	0·9280	0·9098

Solution II; p = 5·46759.

t.	d.	$\alpha_D^{t°}$ (100 mm.).
12·6°	0·9386	−68·631°
*20	0·9325	−68·58
33·2	0·9214	−68·19

t	17·82°	*20°	20·51°
d	0·934323	*0·932501	0932075

Solution III; p = 5·46761.

t.	d.	$\alpha_D^{t°}$ (100 mm.).	t.	d.	$\alpha_D^{t°}$ (100 mm.).
16	0·9357	−71·33	59	0·9005	−68·12
*20	0·9325	−71·04	18·5	0·9337	−71·28
33·5	0·9214	−70·08			

t	19·65°	*20°	20·65°	48·8°	70·4°
d	0·932792	0·932506	0·931974	0·9088	0·8911

Solution IV; p = 5·32411.

14·55	0·9368	−71·59	38·6	0·9173	−69·74
*20	0·9323	−71·20	62·2	0·8979	−67·95
28	0·9259	−70·59			

t	19·28°	*20°	20·2°	20·98°	46·17°
d	0·932913	†0·932316	0·93215	0·931503	0·9108

† This value is calculated from those at 19·28° and at 20·2°. Calculated from those at 19·28° and at 20·98°, the value is 0·932315—a difference of only 1 × 10^{-6} unit.

Second Set of Observations.—The pyknometer was recalibrated with great care, the line representing the change of volume with temperature being determined by the centre of gravity method (Bond, " Probability and Random Errors," Arnold & Co., London, 1935, p. 85 *et seq.*). In eleven observations the greatest difference from this line was only 0·0005 ml., or 1 in 62,750, whilst the error in the estimated position of the mean line must be much less. The volumes at various temperatures were read to the nearest 0·00005 ml.

Similar precautions were taken in making the density measurements. The densities, taken over the temperature range 19·7—20·3°, were plotted on large-scale graphs (1 cm. = 0·00001 in density and 0·05° in temperature), and the position of the mean line representing the change of density with temperature was determined by the centre of gravity method. The density at 20° was finally calculated—not interpolated—from the positions of the centres of gravity. The graphs showed that every determination carried out lay within 2 × 10^{-5} unit of the mean lines: 75 of the 80 determinations lay within 1 × 10^{-5} unit.

It is difficult to estimate exactly the degree of accuracy of the calculated density at 20°, but from a consideration of the possible errors involved, and also empirically from the results obtained, it is believed that the probable error in any one case is less than 5 × 10^{-6} unit, and that the mean values given for M.S.V.'s—for the particular specimens of esters employed—are correct to within ± 0·015 ml.

It may be mentioned that a change of 1 cm. in barometric pressure, if not allowed for, alters the observed density by 16 × 10^{-6} unit, while 1° change in temperature produces an error of 4 × 10^{-6} unit.

The menthyl acetate used had $d_{4°}^{20°}$ 0·925337. Its rotation was $\alpha_D^{20°}$ (100 mm.) − 73·66°, $\alpha_{5461}^{20°}$ (100 mm.) − 86·98°; whence $[\alpha]_D^{20°}$ = − 79·60°, $[\alpha]_{5461}^{20°}$ = − 94·00° (Pickard and Kenyon, J., 1915, **107**, 46, found − 73·57° and − 87·20° respectively).

iso*Butyl* d-*Tartrate.*—Crystallised thrice from benzene, and vacuum-distilled, this had s. p. 72·7° ± 0·05° (if naphthalene sets at 80·1°).

Rotation in pyridine (p = 6·943).

t	13·7°	16·7°	19·8°	*20°	21·7°
d	0·9965	0·9936	0·9906	0·9903	0·9886
$[\alpha]_{5461}^{t°}$	69·72°	68·72°	67·61°	67·65°	67·10°

Densities determined: $d_{4°}^{13·7°}$ 0·9965; $d_{4°}^{16·7°}$ 0·9936; $d_{4°}^{19·8°}$ 0·9906; $d_{4°}^{21·7°}$ 0·9886.

iso*Butyl* l-*Tartrate.*—Purified as above, this had s. p. 72·7° ± 0·05°.

Rotation in pyridine (p = 6·921).

t	15·55°	18·7°	*20°	20·1°	21·7°
d	0·9947	0·9916	0·9903	0·9902	0·9886
$[\alpha]^{t}_{5461}$	−69·19°	−68·12°	−67·7°	−67·69°	−67·09°

Densities determined : $d_{4°}^{17·4°}$ 0·9929; $d_{4°}^{18·7°}$ 0·99155.

iso*Butyl* d-*Tartrate in* l-*Menthyl Acetate*.—The densities recorded for solutions V—XII in Table II were interpolated by calculation from about 5 determinations within the range 19·7—20·3°, as a rule.

Nitrobenzene Solutions.—The density of the nitrobenzene was as follows :

t	19·985°	*20·00°	20·06°	20·20°	20·28°	20·33°
$d_{4°}^{t}$	1·203318	*1·203298	1·203234	1·203103	1·203019	1·202975

The densities recorded for solutions at 20° in Table III were interpolated by calculation from a number (usually 7) determined within about 0·2° of 20°.

The *iso*butyl *d*-tartrate used in these solutions had m. p. 71·7°; $d_{4°}^{80·8°}$ 1·0265, $d_{4°}^{90·3°}$ 1·0178, $d_{4°}^{91·1°}$ 1·0171, $d_{4°}^{94·5°}$ 1·0138. 100 G. of benzene at 20° dissolved 62 g. of the ester.

*iso*Butyl racemate, after crystallisation from benzene, and subsequent distillation at 5—8 mm. pressure, had m. p. 63°; $d_{4°}^{67·6°}$ 1·0386, $d_{4°}^{77·7°}$ 1·0294, $d_{4°}^{85·6°}$ 1·0222, $d_{4°}^{96·4°}$ 1·0122. It dissolved to the extent of 80 g. in 100 g. of benzene at 20°.

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302. *Studies in the Sterol Group. Part XXXIII. The Constitution of the Isomeric Ethers of Cholesterol (Continued from Part XXIX).*

By J. H. BEYNON, I. M. HEILBRON, and F. S. SPRING.

The dextrorotatory ethers of cholesterol are shown to contain an unstable bridge-ring system and to be derived from *i*-cholesterol. The latter exhibits the anomalous reactions towards the halogen acids and bromine previously described as characteristic of the dextrorotatory ethers. Crystallographic data establish that *i*-cholesterol is hydroxylated at C_3; the location of the unstable bridge-ring is discussed.

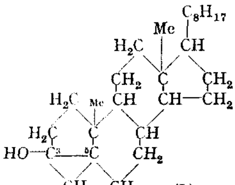
IN an attempt to invert the hydrogen and the hydroxyl group attached to C_3 in the naturally occurring sterols, Stoll ascertained that, whereas cholesteryl *p*-toluenesulphonate reacts with alcohols to give the corresponding normal lævorotatory cholesteryl ethers without stereochemical inversion, yet in the presence of potassium acetate isomeric dextrorotatory ethers are formed (*Z. physiol. Chem.*, 1932, **207**, 147). Wagner-Jauregg and Werner (*ibid.*, 1932, **213**, 119) have also found that cholesteryl chloride reacts similarly, in that with methyl alcohol at 125° in a bomb-tube it is converted into the normal cholesteryl methyl ether, whereas in the presence of potassium acetate the dextrorotatory methyl ether is formed.

The two series of ethers are sharply differentiated in their reactivity; whereas the normal ethers are unaffected by the halogen acids, the dextrorotatory ethers are smoothly converted into the corresponding cholesteryl halides (Beynon, Heilbron, and Spring, J., 1936, 907). Again, with nitric acid, normal cholesteryl methyl ether gives 6-nitrocholesteryl methyl ether, whilst the dextrorotatory ether is converted into 6-nitrocholesteryl nitrate, a result which led us to conclude that both ethers contain an ethylenic linkage at C_5–C_6 (Beynon, Heilbron, and Spring, this vol., p. 406). Stoll (*Z. physiol. Chem.*, 1937, **246**, 14), from a consideration of optical rotatory power, has recently suggested that *allo*cholesterol is the parent of the dextrorotatory methyl ether, and states that the lability of the latter is in favour of this view. It must be emphasised, however, that *allo*cholesterol is not readily

rearranged to cholesterol (Schoenheimer and Evans, *J. Amer. Chem. Soc.*, **1936**, **58**, 182; *J. Biol. Chem.*, 1936, **114**, 567) but tends to undergo dehydration to $\Delta^{2:4}$-cholestadiene. In the same connection we find that, in contradistinction to *allo*cholesterol and its epimer, the dextrorotatory methyl ether fails to give a coloration with the Rosenheim reagent.

A new clue to the nature of the dextrorotatory cholesteryl methyl ether was forthcoming with the observation that it is recovered unchanged after treatment with ozone; again, it does not absorb oxygen from a solution of perbenzoic acid, nor does it give a coloration with tetranitromethane in chloroform solution. These results not only show that this methyl ether is a saturated compound and hence pentacyclic, but lend support to the view expressed by Wallis, Fernholz, and Gephart that the dextrorotatory cholesteryl ethers are related to the recently described *i*-cholesterol, the acetate of which is formed by the action of acetic anhydride upon cholesteryl *p*-toluenesulphonate in the presence of potassium acetate (*J. Amer. Chem. Soc.*, 1937, **59**, 137).

Since Stoll (*loc. cit.*, 1932) has shown that cholesterol is formed by warming cholesteryl *p*-toluenesulphonate with *aqueous* acetone, it is to be expected by analogy that, if the hydrolysis be effected in the presence of an excess of potassium acetate, the parent alcohol of the dextrorotatory cholesteryl methyl ether would be formed. We find that, using these conditions, *i*-cholesterol is obtained in high yield, and its relationship to the dextrorotatory methyl ether is established by its conversion into the latter by direct methylation. In its behaviour *i*-cholesterol closely resembles the dextrorotatory ethers in that, on treatment with the halogen acids or with bromine, it yields the corresponding cholesteryl halide and tribromocholestane respectively (cf. Beynon, Heilbron, and Spring, *loc. cit.*, 1936). The recognition of the pentacyclic nature of the isomeric cholesteryl ethers and of *i*-cholesterol leaves unsettled their molecular configuration. We cannot subscribe to the provisional structure proposed by Wallis, Fernholz, and Gephart (*loc. cit.*), which is based upon the observation that on oxidation of *i*-cholesterol with chromic acid a ketone was isolated (as oxime). In view of the susceptibility of *i*-cholesterol to rearrangement, this evidence cannot be taken to indicate the presence of a secondary hydroxyl group.



(I.)

A crystallographic examination of *i*-cholesterol and its derivatives, undertaken at our request by Miss F. Bell, B.A., in the Physics Department of this University, has unequivocally demonstrated that the hydroxyl group of the former is attached to C_3; the detailed results of this investigation will be communicated later. In view of the lability of the C_3-alkoxy-group in the *i*-cholesteryl ethers, and the ease with which *i*-cholesterol derivatives are isomerised to the corresponding derivatives of cholesterol (Δ^5), it is tempting to postulate that *i*-cholesterol contains a labile bridge joining C_3 and C_5 (I). Experiments designed to test the validity of this representation are in progress.

Experimental.

i-*Cholesteryl Acetate*.—A solution of cholesteryl *p*-toluenesulphonate (3 g.) and anhydrous potassium acetate (4 g.) in aqueous acetone (100 c.c.; 50%) was heated under reflux for 6 hours. The oil separating on dilution with water was isolated by means of ether and heated for 2 hours with alcoholic potassium hydroxide solution (60 c.c.; 5%), diluted with water, and extracted with ether. After removal of the solvent from the washed and dried extract, the residual oil was taken up in warm 90% alcohol (15 c.c.) and set aside overnight with a solution of digitonin in 90% alcohol (500 c.c.; 1%). The separated digitonide was collected, and the solvent removed from the filtrate under diminished pressure. The residual solid was triturated with cold ether, the ethereal extract washed with water, and dried (sodium sulphate). After removal of the solvent, the crude *i*-cholesterol was heated on the steam-bath for 2 hours with acetic anhydride (20 c.c.), and the solid separating on cooling was crystallised from alcohol, from which *i*-cholesteryl acetate (1·2 g.) separated in clusters of needles, $[\alpha]_D^{20°} + 48·1°$ ($l = 1$, $c = 1·6$ in chloroform), m. p. 73° showing no depression on admixture with that obtained by the method of Wallis, Fernholz, and Gephart (*loc. cit.*) (Found: C, 81·4; H, 11·1. Calc. for $C_{29}H_{48}O_2$:

C, 81·2; H, 11·3%). *i*-Cholesteryl acetate is more soluble than cholesteryl acetate in the usual organic solvents; it does not give a coloration with tetranitromethane or antimony trichloride in chloroform, or with the Rosenheim reagent.

i-*Cholesterol*.—*i*-Cholesteryl acetate (1 g.) was heated under reflux for 1 hour with alcoholic potassium hydroxide solution (40 c.c.; 4%). The oil separating on dilution with water was isolated by means of ether and crystallised from alcohol at $-10°$, *i*-cholesterol being obtained in needles, $[\alpha]_D^{20°} + 27°$ ($l = 1$, $c = 1·6$ in chloroform), m. p. 68—69°, not depressed on admixture with that obtained by the method of Wallis, Fernholz, and Gephart (*loc. cit.*) (Found: C, 84·0; H, 11·7. Calc. for $C_{27}H_{46}O$: C, 83·8; H, 12·0%).

Cholesteryl Chloride from i-*Cholesterol*.—A solution of *i*-cholesterol (0·1 g.) in glacial acetic acid (30 c.c.) was treated with concentrated hydrochloric acid (0·1 c.c.). After standing at room temperature overnight, the mixture was diluted with water, and the resulting solid was crystallised from acetone, from which cholesteryl chloride separated in laminæ, $[\alpha]_D^{20°} - 27·0°$ ($l = 1$, $c = 1$ in chloroform), m. p. 95°, unchanged by admixture with an authentic specimen.

Tribromocholestane.—A solution of bromine in ether (15 c.c.; 1%) was added to *i*-cholesterol (0·1 g.) in ether (40 c.c.), and the mixture set aside at room temperature for 12 hours. The solvent was removed from the colourless solution, and the residue crystallised from alcohol to give tribromocholestane in prisms, $[\alpha]_D^{20°} - 49·0°$ ($l = 1$, $c = 1·08$ in chloroform), m. p. 112—113°, not depressed by admixture with an authentic specimen.

Methylation of i-*Cholesterol*.—*i*-Cholesterol (0·5 g.) was added to a suspension of finely divided potassium (0·2 g.) in dry benzene (30 c.c.), and the mixture heated under reflux for 1 hour. After addition of methyl iodide (30 c.c.), the heating was continued for a further 4 hours. Treatment with alcohol, followed by removal of the solvent mixture under diminished pressure, gave a solid which was extracted with ether, the extract washed with water, and dried (sodium sulphate). The oil obtained after removal of the solvent was crystallised from acetone, giving *i*-cholesteryl methyl ether in needles, $[\alpha]_D^{19°} + 54°$ ($l = 1$, $c = 1·3$ in chloroform), m. p. 79°, not depressed in admixture with the dextrorotatory cholesteryl methyl ether prepared by the method of Stoll (*loc. cit.*, 1937) (Found: OMe, 7·8. Calc. for $C_{28}H_{48}O$: OMe, 7·75%).

We are indebted to the Department of Scientific and Industrial Research for a Senior Research Award to one of us (J. H. B.), and to Imperial Chemical Industries, Ltd., for a grant.

The University, Manchester. [*Received, July 3rd, 1937.*]

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303. *Properties of the Oxides of Nitrogen. Part VI. Flame Propagation in the System Nitric Anhydride–Ozone.*

By (the late) T. M. Lowry and R. V. Seddon.

Mixtures of nitric anhydride, ozone, and oxygen were ignited in a long reaction tube, and the time required for the flame to travel along a column 90 cm. long, maintained at a constant temperature, was measured. *The speed of the flame is extremely* sensitive to changes of conditions: *e.g.*, (*a*) the concentrations of anhydride and ozone and the "age" of the mixtures; (*b*) the temperature of the tube and the total pressure; (*c*) the diameter of the tube and its horizontal or vertical position; (*d*) the nature and concentration of the inert gas.

The flame is propagated by the diffusion of "hot" molecules from the flame-front into the unburnt gas causing activation and further reaction.

Part V (J., 1936, 1409) described a few experiments on the flame produced by igniting a mixture of dinitrogen pentoxide (nitric anhydride) and ozonised oxygen in a long combustion tube; a mechanism was suggested for the reaction, and a few determinations of flame speed made. The present work describes a method for preparing gaseous mixtures of known composition, and a technique for measuring flame speeds accurately. A thorough study was made of the variation of flame speed with (*a*) the "age" of the mixture, (*b*) concentration of ozone or nitric anhydride, (*c*) the temperature of the combustion tube,

(*d*) diameter of tube, (*e*) direction of propagation, *i.e.*, upward, downward, or horizontal, (*f*) the nature and concentration of the inert gas.

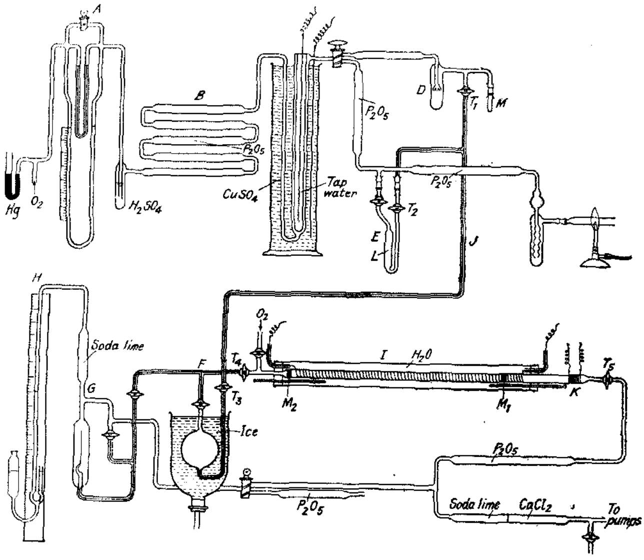
The observed results are explained on the basis of a simple kinetic theory involving propagation of the flame by the *diffusion* of " hot " molecules from the flame front into the unburnt gases causing activation and catalysing further reaction. The actual reactions taking place in the flame front, involving the formation of the unstable intermediate product NO_3, will be dealt with in a later paper when the slow reaction between the gases has been investigated.

Experimental.

Preparation and Purity of Materials.—Ozonised oxygen (12% by weight) was prepared from ordinary cylinder oxygen, which was thoroughly dried before and after passing through the ozoniser.

The liquid nitrogen tetroxide used in the preparation of the pentoxide was a specially purified sample supplied in Carius tubes by Imperial Chemical Industries Ltd. (Nobel's section).

Fig. 1.



2 or 3 C.c. of this liquid were distilled through phosphoric oxide into the reaction vessel *D* (Fig. 1); the U-tube *E* was attached to the ground glass joint at *M*, ozonised oxygen passed over the tetroxide at room temperature, and the pentoxide formed frozen out into limb *L* of the U-tube by means of solid carbon dioxide in alcohol. Traces of nitrogen peroxide were removed from the pentoxide by allowing the U-tube to warm up, and passing oxygen through until all brown fumes disappeared. The U-tube was then attached to the apparatus as shown, and kept in solid carbon dioxide and alcohol.

A stream of dry oxygen, of known rate of flow, was passed through the U-tube containing the pentoxide kept at constant temperature, and the amount of the pentoxide taken up was

measured by absorption in concentrated potassium hydroxide solution. The "apparent" vapour pressure was calculated for various rates of flow, and the true vapour pressure obtained by extrapolation to zero rate. The values obtained for various temperatures are given below,

Temp.		−11·0°	0·0°	10·8°
Vapour press., mm.	Measured	17	48	139·5
	Obtained by other workers	17	50	136

being compared in the third line with interpolated values from measurements made by Russ and Pokorny (*Monatsh.*, 1913, **34**, 1051) below 10·5° and by Daniels and Bright (*J. Amer. Chem. Soc.*, 1920, **42**, 1131) above 10·5°.

Preparation of Mixtures of Nitrogen Pentoxide and Ozone, and Measurement of Flame Speeds.—In order to secure definite concentrations of the pentoxide and of ozone, it was necessary to abandon the attempt to saturate ozonised oxygen with the vapour, and to prepare the mixtures in a mixing-bulb surrounded with ice. The apparatus is shown in Fig. 1. The oxygen drying and ozonising system B was essentially the same as that used by Lowry and Lemon (J., 1935, 692). A flow-meter A, using sulphuric acid, was introduced in order to keep careful control over the rate of flow of oxygen through the ozoniser: a good needle valve on the oxygen cylinder enabled this to be done. Careful measurements were made on the variation of the proportion of ozone produced for various rates of flow. The ozone content was found to change by only 1% for a change of 80 c.c./min. in the rate of flow, over the range 0—300 c.c./min. The rate was normally kept constant at 198 ± 3 c.c./min. Measurements were also made on the variations caused by change of voltage on the ozoniser. The proportion rises to a fairly flat maximum at 7500 ± 8000 volts. Normally the voltage was kept constant at 7500 ± 100 volts, and with the above-mentioned rate of flow of oxygen the ozone content was 11·1% by weight. Since a mercury manometer cannot be used directly with these highly corrosive gases, a Bourdon gauge G, used as a null instrument, was inserted between the mixing bulb F and the manometer H. The mixing bulb (1 l. capacity) was kept in melting ice. The reaction vessel I was a long, soda-glass tube of 11·7 mm. internal diameter, wound with a nichrome heating coil and surrounded by a water jacket. The temperature of the jacket read on two thermometers was constant to 0·1°, and was maintained at 20°. A small heating coil K was used for igniting the gas mixture. The apparatus was washed out with dry oxygen, and could be evacuated down to 1 cm. pressure by means of two filter pumps.

Manipulation was as follows. The reaction tube, mixing bulb, gauge, manometer, and U-tube were evacuated down to 1 cm. pressure; stopcock T_4 was closed and the U-tube allowed to warm up until the required pressure of nitric anhydride (usually 30 mm.) was attained in the mixing bulb; T_3 was then closed, and the stock of anhydride again frozen. The ozoniser was started, and the rate of flow of oxygen and the applied voltage carefully regulated to the normal working values mentioned above. With stopcock T_2 open, ozonised oxygen was slowly drawn off at J from the main stream, T_3 being used for control. It required 5 minutes to obtain a pressure of 675 mm. of ozonised oxygen equivalent to 50 mm. of ozone. On the ninth minute, stopcock T_8 was closed, and the mixture admitted to the reaction tube; then T_4 was closed, and the mixture ignited on the tenth minute. The time for the flame to travel from mark M_1 to M_2, 90 cm., was measured with a stop-watch reading to 0·2 second. The reaction tube was immediately evacuated, and a second charge of mixture admitted on the 14th and ignited on the 15th minute. Four or five "runs" could be done before the total pressure or ozone content became too low to give the flame.

A test was made on the uniformity of movement of the flame. A mark M_3 was made on the combustion tube equidistant from M_1 and M_2, and the velocity of the flame measured over the first and the second half of the run by means of two stop-watches. The speeds were identical.

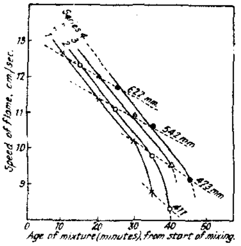
Age of Mixtures.—In order to determine the effect on the flame speed of the progressive decomposition of the mixture, the mixing bulb was charged initially with 30 mm. of nitric anhydride, to which ozonised oxygen was added to give 50 mm. of ozone, with oxygen to a total pressure of 715 mm. On admission of this mixture to the exhausted combustion tube, the pressure in the tube fell in successive experiments to 622, 542, 473, and 411 mm., and the velocity of the flame was measured at each of these pressures. The influence of age was then determined by beginning further series of experiments after increased intervals from the moment when ozone was first admitted to the bulb.

The results are shown graphically in Fig. 2. Each result is the average of three measurements which did not differ by more than 0·3 cm./sec. When points representing equal pressures,

in different series are joined, the velocity of the flame is seen to fall off in a linear manner with the age of the mixture; but whereas at 622 and 542 mm. the decrease is constant at about 0·06 cm./sec. for each minute of ageing, this rate increases to about 0·08 at 473 mm. pressure and to 0·11 at 411 mm. The results thus obtained were confirmed by measurements in which the pressure in the first of a series of experiments was reduced to 542, 473, or 411 mm.

Influence of Concentration of Ozone on Speed of Flame.—The velocity of the flame is extremely sensitive to the concentration of ozone. In two series of experiments 30 mm. and 15 mm. of pentoxide were mixed with ozonised oxygen to a maximum of 50 mm. of ozone, which was then reduced by 1 mm. steps by adding oxygen in place of ozonised oxygen. The flame speed was then determined for a series of pressures, and corrected for the ageing of the mixtures. In correcting these and all other results, the zero time was taken as 2½ mins. from the start of mixing, since the completion of this process required 5 mins. The results are shown in Fig. 3, where the flame speed is plotted against the pressure of ozone for various values of the total pressure. The upper series of curves are for 30 mm. of pentoxide, and the lower series for 15 mm. The effects are remarkable, since with 30 mm. a reduction of only 5 mm. in the pressure of ozone reduces the velocity of the flame from 12·5 cm./sec. to 9·8 cm./sec. at a total pressure of 622 mm., and all the other curves show a still more rapid decrease of velocity as the partial pressure of the ozone is reduced.

FIG. 2.

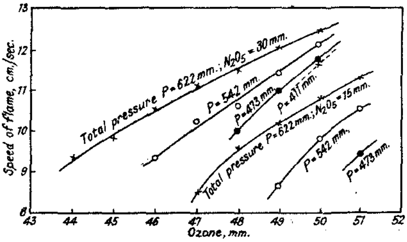


Influence of ageing on speed of flame.

The upper portions of the curves tend towards straight lines, but fall off more and more rapidly as the ozone content decreases, until finally the flame can no longer be propagated at velocities less than 8 cm./sec. The curves for 15 mm. of pentoxide resemble the lower portions of the curves for 30 mm.

Calculation shows that the fall of velocity with the age of the mixture may be attributed directly to loss of ozone. It has already been shown (above) that at a total pressure of 622 mm.

FIG. 3.



Influence of concentration of ozone on speed of flame.

with 30 mm. of pentoxide and 50 mm. of ozone the speed of the flame falls off at the rate of 0·06 cm./sec. in each minute, whilst the ozone content falls off at the rate of 0·14 mm./min. (from later work on the " slow reaction "). Division of the first by the second shows that the reduction in the flame speed for 1 mm. loss of ozone should be 0·0610 ÷ 0·14 = 0·43 cm./sec. The experimental figure, *i.e.*, the gradient of the 622-mm. curve in Fig. 3, is found to be 0·4—0·45 cm./sec.

Influence of Concentration of Nitric Anhydride.—Nitric anhydride (10—50 mm.) was admitted to the mixing bulb, and then ozonised oxygen to give 50 mm. of ozone. Not less than two concordant determinations of flame speed were made for each set of pressures. The results are shown graphically in Fig. 4. The corrected velocities rise to a maximum at a concentration of pentoxide which is almost constant at about 30 mm., *i.e.*, rather more than one half of the partial pressure of the ozone.

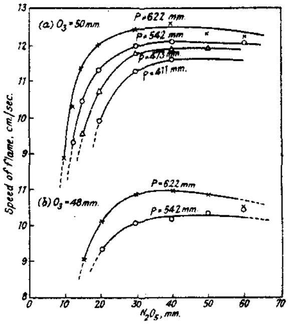
It seems clear that the very rapid rise in flame speed at the beginning is due to the increasing amount of "fuel," all of which is burnt up. With a fixed amount of ozone, only a definite quantity of the anhydride can be consumed, and any excess merely acts as inert gas, resulting in the flattening out of the curves.

Influence of Temperature on Speed of Flame.—A first series of experiments with the optimum mixture was made at 20—40° under pressures of 622, 542, and 473 mm. The velocity fell off slowly from a flat maximum at about 20°, until the temperature reached 30°, after which it decreased very rapidly indeed, because of rapid destruction of ozone in the reaction tube in presence of nitric anhydride prior to ignition.

After this series of measurements had been completed, it was found that the values at 20° were no longer reproducible, until the tube had been taken down and washed with nitric acid and water as before. It is to be concluded that the surface plays a part in determining the flame speed, and that heating changes the properties of the surface.

The reaction tube was cooled by circulating water through the outer jacket, and a second series ranging from 0—30°, after the tube had been washed out with nitric acid, gave concordant results, but these were a little lower than those of the first series. They show a well-marked maximum at about 20°, but fall off rather less steeply at lower than at higher temperatures. Several months separated the two sets of results, and there had been a gradual drift in the absolute values obtained, probably due to the changing surface conditions. The results are plotted in Fig. 5.

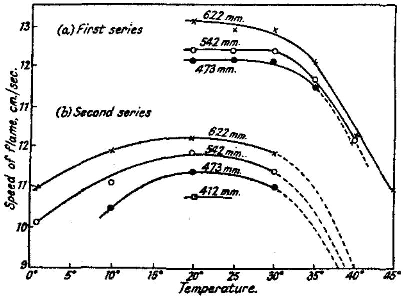
Fig. 4.



Influence of concentration of N_2O_5 *on speed of flame.*

Influence of Diameter of Tube on Speed of Flame.—The main series of observations was made with tubes of different diameter selected from a uniform batch of soda-glass. In order to secure

Fig. 5.



Influence of temperature on speed of flame.

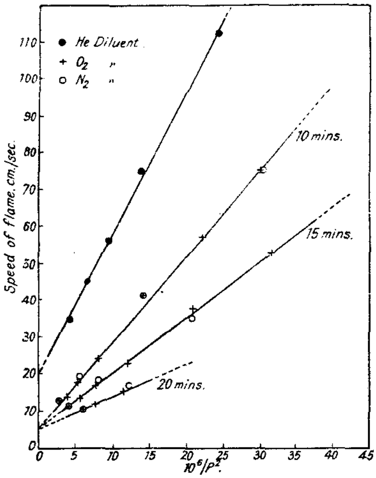
a uniform surface the tubes were washed with (i) concentrated nitric acid, (ii) tap water, (iii) distilled water, and (iv) methyl alcohol, and then dried in a current of air. The tube was sealed on to the apparatus, washed with dry oxygen and evacuated twice, then filled with oxygen and allowed to stand overnight. Even with this standardised treatment, the results obtained were rather variable, but they show that the flame speed is approximately directly proportional to the diameter of the tube. The internal diameters of the tubes ranged from 13·45 to 8·40 mm.; the flame, however, could not be produced in tubes of less than 10 mm. diameter. Some experi-

ments were carried out in soda-glass tubes of similar diameter but from different lots of glass. The results obtained bore no relation to the main series.

Flame Speeds in Upward, Downward, and Horizontal Directions.—The tubes used in the preceding experiments were cleaned and used again, first in a vertical position then horizontally. The velocity of the flame in the downward direction is two-thirds of that in the upward direction on account of convection. The downward velocity decreases with the diameter of the tube, but the upward velocity is independent of diameter. The results in the horizontal tubes are similar to those for upward propagation, but in the largest tube (13·45 mm.) the velocity horizontally is definitely greatest.

The Influence of the Inert Gas on the Flame Speed.—An apparatus was constructed for the preparation of liquid ozone, similar to the one used by Norrish and Neville (J., 1934, 1864). It

FIG. 6.



Effect of inert gas on speed of flame.

was attached to the main apparatus (Fig. 1) at *M*, so that mixtures containing a higher percentage of ozone could be obtained. The liquid ozone was analysed before use, and the ozone content found to vary from 80 to 85% with different preparations. It was now possible to obtain mixtures of ozone and nitric anhydride with any desired pressure of oxygen or other inert gas. The nitric anhydride was admitted to the bulb first, then the highly concentrated ozone, and lastly various amounts of oxygen, nitrogen, or helium. The flame speeds for these mixtures were measured in the usual way; they are plotted against the reciprocal of the square of the total pressure in Fig. 6. The lowest three curves are for mixtures ignited on the 10th, 15th, and 20th minutes respectively. The flame speed rises rapidly as the amount of inert gas decreases and is inversely proportional to the square of the total pressure. With nitrogen and oxygen, the flame speeds are identical, but with helium they are much greater at corresponding pressures. Bone and Outridge (*Proc. Roy. Soc.*, 1936, *A*, 157, 234) recently obtained similar results for mixtures of acetylene or ethylene and oxygen with the inert gases nitrogen and argon: the flame speeds rapidly increased as the amount of inert gas in the mixture decreased.

The Luminous Flame.—At the lowest pressures used, *i.e.*, when no inert gas had been added, the mixture could not be ignited in the usual way. If the heating coil *K* (Fig. 1) was switched

on, nothing happened; when, however, stopcock T_5 was opened and the mixture began to be slowly pumped out, a flame, which was easily seen to be luminous in full daylight, shot along the tube at a speed too rapid to be measured by means of the stop-watch. This luminous flame was examined in the dark, and it was found that mixtures containing quite large amounts of inert gas also gave a luminous flame. All the latter mixtures could be ignited directly by the heating coil K. Tests on the quenching of this luminosity showed that a mixture containing 30 mm. of anhydride, 50 mm. of ozone, and 414 mm. of oxygen (total pressure, 407 mm. when admitted to the reaction tube) gave a flame which could not be detected with the naked eye in the dark. A mixture containing 30 mm. of anhydride, 50 mm. of ozone and 314 mm. of oxygen, which gave a pressure of 324 mm. in the reaction tube, gave a flame which could only just be detected as a very faint, hemispherical, yellow glow in the dark. A mixture of the same composition but with helium instead of oxygen gave a flame easily seen in the dark. The blue band could still be seen at the flame front even when the luminosity was present. It seems probable that the luminosity is due to reaction products, *i.e.*, nitrogen dioxide, excited by the energy liberated in the reaction, while the quenching of the luminosity is to be ascribed to the rapid dissipation of the energy by the inert gas. Oxygen, with a larger number of degrees of freedom, is far more effective in this respect than helium.

DISCUSSION.

The greater flame speed in the upward than in the downward direction is accounted for by convection, and shows that a considerable amount of heat is evolved in the reaction.

The flame speed is very sensitive to small changes in the ozone concentration, and under the conditions of the experiments the flame could not be obtained with mixtures containing less than 44 mm. of ozone as compared with a maximum of 50 mm. given by the ozoniser. In the propagation of the flame the ozone is probably activated first, by hot molecules from the flame front, and then reacts with the nitric anhydride. The gradual falling off in flame speed with the ageing of the gas mixture is due to slow destruction of ozone.

The nitric anhydride can be regarded as the " fuel " and as the concentration increases the flame speed rises rapidly, reaches a maximum, and falls off gradually since excess fuel will act as inert gas.

The flame speed is roughly proportional to the diameter of the reaction tube, and the flame cannot be obtained in tubes of less than 10 mm. diameter. The surface has a specific effect and plays a minor part in determining the flame speed, possibly by acting as an acceptor of excess energy from the hot molecules.

The effect of the inert gas and the rapid rise of flame speed as the pressure decreases can be accounted for on the basis of Fick's law of diffusion (*Pogg. Ann.*, 1855, **94**, 59), *viz.*, $ds = -Dq(dc/dx) \, . \, dt$, where ds is the amount of substance which diffuses across an area q in time dt, D is the coefficient of diffusion and dc/dx the concentration gradient of the diffusing gas. The coefficient of diffusion can be approximately expressed as $D = \frac{1}{3}\bar{C}L$, where $\bar{C}$ is the velocity and L the mean free path; L, and hence D, is inversely proportional to the pressure. The gradient of concentration of active molecules at the flame front will also be inversely proportional to pressure; hence the flame speed will vary inversely as the square of the total pressure, in accordance with the observed result. Theory predicts that D will vary as $T^{3/2}$, and at 0° it will increase by a factor of 1·06 for 10° rise in temperature. Experiments on diffusion, however, show that the factor varies from 1 to 1·5, and in our experiments (see Fig. 5) from 0° to 10° the flame speed increases by a factor of 1·2 for the highest pressure. At higher temperatures, unfortunately, measurement of the dependence of flame speed on temperature is vitiated by the instability of the mixture and no accurate estimate of the rate of change can be made. The coefficient of diffusion for oxygen into helium has been shown to be higher by a factor of 3 or 4 than for the same gas diffusing into nitrogen (Loeb, " Kinetic Theory of Gases "). With this fact the higher flame speeds obtained with helium as diluent are in qualitative agreement, the ratio of speeds in helium and nitrogen being approximately 2. It may therefore be concluded that the propagation of the flame is due to the diffusion of " hot " molecules from the flame front into the unburnt gases causing activation and further reaction.

In 1883 Mallard and Le Chatelier expressed the view that flame propagation during the uniform movement is due to " the cold mixture immediately in front of the flame being

raised to its ignition temperature by conduction of heat from the burning and burnt layers immediately behind the flame front." They obtained the following formula for the velocity of flame propagated in this way:

$$V = [L(T - t)/C(t - \theta)][f(T, t)]$$

where T = temperature of combustion, t = ignition temperature, θ = initial temperature, L = thermal conductivity of unburnt gas, C = mean specific heat of the burning or just-burnt gas, and $f(T, t)$ = a constant.

On this formula, however, the effect of removing the inert gas would be to lower the thermal conductivity L of the unburnt gas and cause a decrease in the flame speed. Bone, Fraser, and Winter ("Flame and Combustion in Gases," Bone and Townend) have carried out experiments on the relative effects of helium, argon, and nitrogen on the flame speeds for mixtures of acetylene and oxygen, and obtained similar results to those of Coward and Hess on the methane–oxygen flame. The flame speeds for mixtures containing helium or argon are much greater than for mixtures containing nitrogen, and they attribute this to the difference in thermal conductivity of the mixtures. In the light of our present work, this explanation is open to criticism.

The mechanism that we have deduced for the propagation of the flame is equivalent to an energy chain in which liberated energy is passed on directly from resultants to reactants.

Preliminary investigation of the slow reaction between ozone and nitric anhydride showed that the mixture contained NO_3, which is probably the intermediate product in the catalysed decomposition of ozone. The reactions involved must closely resemble those taking place in the flame, and these will be discussed when the slow reaction has been thoroughly investigated.

We are indebted to Professor R. G. W. Norrish for suggesting the diffusion mechanism and for many helpful discussions, and to Imperial Chemical Industries, Limited, for grants for maintenance and apparatus.

University Chemical Laboratory, Cambridge. [*Received, March 1st, 1937.*]

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304. *Polyamines. Part III. The Preparation of Unsymmetrical Amines of the Types* $NHR{\cdot}C_2H_4{\cdot}NH{\cdot}C_2H_4{\cdot}NH_2$ *and* $NH_2{\cdot}C_2H_4{\cdot}NH{\cdot}C_3H_6{\cdot}NH_2$, *and the Action of Ammonia on Di*-p-*toluenesulphonylbis-(β-chloroethyl)ethylenediamine.*

By D. H. Peacock and Yeo Sein Gwan.

Unsymmetrical amines of the types mentioned above are of obvious interest for the preparation of co-ordination compounds with metals. The toluenesulphonamides of three of these have been prepared: $CH_3{\cdot}C_6H_4{\cdot}SO_2{\cdot}N(CH_2Ph){\cdot}C_2H_4{\cdot}NH{\cdot}C_2H_4{\cdot}NH_2$, $CH_3{\cdot}C_6H_4{\cdot}SO_2{\cdot}NEt{\cdot}C_2H_4{\cdot}NH{\cdot}C_2H_4{\cdot}NH_2$, $CH_3{\cdot}C_6H_4{\cdot}SO_2{\cdot}NH{\cdot}C_3H_6{\cdot}NH{\cdot}C_2H_4{\cdot}NH_2$, and in some cases the corresponding tetramines have been prepared. By the action of ethylene oxide on di-*p*-toluenesulphonylethylenediamine, di-*p*-toluenesulphonyl-*NN'*-bis-(β-hydroxyethyl)ethylenediamine was prepared, and from it the corresponding chloro-compound by the action of thionyl chloride. This chloro-compound when treated with ammonia gave the di-*p*-toluenesulphonyl derivatives of *NN'*-bis-(β-aminoethyl)ethylenediamine and of a new cyclic polyamine.

Bases of the type $NHR{\cdot}C_2H_4{\cdot}NH{\cdot}C_2H_4{\cdot}NH_2$ should form co-ordination compounds of obvious stereochemical interest. We have prepared the *p-toluenesulphonyl* derivatives (I; R = CH_2Ph or Et, R' = $NH{\cdot}C_2H_4{\cdot}NH_2$) of two of these by the action of ethylenediamine upon the corresponding *chloro*-compounds (I; R = CH_2Ph or Et, R' = Cl), which were prepared from the *hydroxy*-compounds (I; R' = OH) by the action of thionyl chloride. The chloro-compounds reacted much more slowly with ethylenediamine than

did *p*-toluenesulphon-β-chloroethylamide (Peacock, J., 1936, 1518). The compound (I; R = CH_3, R′ = OH) has been prepared by Slotta and Behnisch (*J. pr. Chem.*, 1932,

$$\underset{\text{(I.)}}{T{\cdot}NR{\cdot}CH_2{\cdot}CH_2R'} \qquad \underset{\text{(II.)}}{T{\cdot}NH{\cdot}C_3H_6R} \qquad \underset{\text{(III.)}}{T{\cdot}NH{\cdot}[CH_2]_n{\cdot}NH{\cdot}[CH_2]_m{\cdot}NH_2}$$

(T = *p*-Toluenesulphonyl.)

135, 225), and the corresponding bromo-compound (I; R = CH_3, R′ = Br) by Marckwald and Frobenius (*Ber.*, 1901, **34**, 3544). The compound (I; R = CH_2Ph, R′ = OH) was heated with aluminium chloride but no tetrahydro*iso*quinoline could be isolated from the tarry reaction product.

$$\underset{\text{(IV.)}}{\begin{matrix}T{\cdot}NH{\cdot}[CH_2]_n{\cdot}NH \\ T{\cdot}NH{\cdot}[CH_2]_n{\cdot}NH\end{matrix}{>}[CH_2]_m} \qquad \underset{\text{(V.)}}{C_2H_4{<}\begin{matrix}NT{\cdot}C_2H_4R \\ NT{\cdot}C_2H_4R\end{matrix}} \qquad \underset{\text{(VI.)}}{C_2H_4{<}\begin{matrix}NT{\cdot}C_2H_4R \\ NTH\end{matrix}}$$

When *p*-toluenesulphon-β-chloroethylamide (Slotta and Behnisch, *loc. cit.*; Peacock and Dutta, J., 1934, 1303) was heated with trimethylenediamine, two hydrochlorides were obtained; one was the *dihydrochloride* of (IV; $n = 2$, $m = 3$), and the other appeared to be the *trihydrochloride* of the base (III; $n = 2$, $m = 3$); there seems no strong reason why this base should form a trihydrochloride, but this behaviour is not unprecedented, for the benzoyl derivative of ββ′-dibromodiethylamine forms salts with acids (Peacock and Dutta, *loc. cit.*). *p*-Toluenesulphon-γ-hydroxypropylamide (II; R = OH) was prepared in the usual way, and the crude compound converted into the *chloro*-compound (II; R = Cl). This, when heated with ethylenediamine, gave the *hydrochlorides* of the bases (III and IV; $n = 3$, $m = 2$). The free base corresponding with the latter has been prepared by van Alphen (*Rec. trav. chim.*, **1937**, **56**, 343).

By the action of ethylenechlorohydrin or of ethylene oxide on di-*p*-toluenesulphonylethylenediamine, the substances (V and VI; R = OH) were obtained, which were respectively insoluble and soluble in sodium hydroxide. The former, NN′-*di*-p-*toluenesulphonyl*-NN′-*bis*-(β-*hydroxyethyl*)*ethylenediamine*, was obtained in the pure state, only one form being isolated; if the three valencies of nitrogen are not in one plane, two forms

$$\underset{\text{(VII.)}}{NH{<}\begin{matrix}C_2H_4{\cdot}NT \\ C_2H_4{\cdot}NT\end{matrix}{>}C_2H_4} \qquad \begin{matrix}\underset{\text{(VIII.)}}{C_2H_4(NH{\cdot}C_2H_4{\cdot}NH_2)_2} \\ \\ \underset{\text{(IX.)}}{NHT{\cdot}C_2H_4{\cdot}NH{\cdot}C_2H_4{\cdot}NH{\cdot}C_2H_4{\cdot}NH_2,3HCl}\end{matrix}$$

should be capable of existence, *meso*- and *dl*-; the same remarks also apply to compounds (V; R = Cl) and (V; R = NH_2). The hydroxy-compounds corresponding with (V) and (VI) were converted in the usual way into the *chloro*-compounds. When (V; R = Cl) was heated with aqueous ammonia, the *dihydrochloride* of (V; R = NH_2) was obtained, and the *monohydrochloride* of a *base* which was almost certainly (VII). Similar cyclic bases have been obtained by van Alphen (*loc. cit.*). The amino-compound (V; R = NH_2) on hydrolysis gave the tetrahydrochloride of *NN*′-bis-(β-aminoethyl)ethylenediamine (VIII) (Hofmann, *Proc. Roy. Soc.*, 1862, **11**, 413; Peacock, J., 1936, 1518; van Alphen, *Rec. trav. chim.*, 1936, **55**, 412).

p-Toluenesulphon-β-chloroethylamide, when heated with an alcoholic solution of ββ′-diaminodiethylamine, gave a *trihydrochloride*, probably that of *p*-toluenesulphonyl-*NN*′-bis-(β-aminoethyl)ethylenediamine (IX).

Experimental.

The Action of Ethylenediamine on p-*Toluenesulphonbenzyl*-β-*chloroethylamide* (I; R = CH_2Ph, R′ = Cl).—The *substance* (I; R = CH_2Ph, R′ = Cl), prepared from the hydroxy-compound (Peacock and Dutta, *loc. cit.*) by the action of thionyl chloride and pyridine, crystallised from methyl alcohol; m. p. 69° (Found: Cl, 11·1. $C_{16}H_{18}O_2NSCl$ requires Cl, 11·0%). When this compound was boiled under reflux with an ethyl-alcoholic solution of ethylenediamine for 10 hours no reaction took place; but when the compound (12·8 g.), ethylenediamine (2·4 g.), and amyl alcohol (50 c.c.) were heated under reflux in an oil-bath at 140—145° for 12 hours,

ethylenediamine dihydrochloride was precipitated. This was filtered off, the amyl alcohol distilled off, the residue extracted with boiling dilute hydrochloric acid, and the extracts evaporated to dryness; the product (5·6 g.), a mixture of the dihydrochlorides of ethylenediamine and of the base (I; R = CH_2Ph, R′ = $NH{\cdot}C_2H_4{\cdot}NH_2$), was purified by extraction with alcohol, in which the former salt was practically insoluble. The latter *dihydrochloride* crystallised from absolute alcohol, m. p. 149—150° (Found: Cl, 16·6. $C_{19}H_{25}O_2N_3S,2HCl$ requires Cl, 16·9%). The oily residue, insoluble in dilute hydrochloric acid, was extracted with glacial acetic acid; two products were isolated, m. p. 114° and 140°. The second product, crystallised from a mixture of methyl alcohol, water, and hydrochloric acid, had m. p. 141—142°, and appeared to be the *hydrochloride* of NN′-*bis*-(β-p-*toluenesulphonbenzylamidoethyl*)*ethylenediamine* (Found: Cl, 5·0, 5·16. $C_{34}H_{42}O_4N_4S_2,HCl$ requires Cl, 5·3%).

Ethylenediamine and p-*Toluenesulphon*-(β-*chloroethyl*)*ethylamide* (I; R = Et, R′ = Cl).—By the action of either ethylene chlorohydrin or ethylene oxide on the sodium derivative of *p*-toluenesulphonethylamide, the compound (I; R = Et, R′ = OH) was obtained. The yields were poor, about 40%, and the compound could not be obtained crystalline. When it (36 g.) was treated with thionyl chloride (26 g.) and pyridine (11·9 g.) in carbon tetrachloride (50 c.c.) at 7°, heated slowly to 85°, and the product worked up in the usual way, it afforded the *compound* (I; R = Et, R′ = Cl) (21 g.), which, crystallised from ether–light petroleum, had m. p. 67° (Found: Cl, 13·2. $C_{11}H_{16}O_2NSCl$ requires Cl, 13·6%). This chloro-compound did not react with ethylenediamine in ethyl-alcoholic solution, but in amyl-alcoholic solution in an oil-bath at 140—150°, it afforded a viscous product. When worked up in the usual way, this did not give a crystalline hydrochloride, but when heated with *p*-toluenesulphonyl chloride, it gave the *tri*-p-*toluenesulphonyl* derivative of N-β-*aminoethyl*-N′-*ethylethylenediamine* (cf. I; R = Et, R′ = $NH{\cdot}C_2H_4{\cdot}NH_2$), m. p. 203° (Found: S, 15·7. $C_{27}H_{35}O_6N_3S_3$ requires S, 16·2%), from glacial acetic acid.

Ethylenediamine and p-*Toluenesulphon*-γ-*chloropropylamide* (II; R = Cl).—*p*-Toluenesulphonamide (85·5 g.) was converted into the dry sodium salt, mixed with trimethylene chlorohydrin (42·3 g.), and heated, in a flask fitted with a mercury seal, in an oil-bath at 160—170° for 13 hours. The product was extracted with ethyl alcohol, filtered from sodium chloride, and sodium (1·15 g.) added to the solution, which was then evaporated to dryness. Trimethylene chlorohydrin (4·2 g.) was added, and the mixture heated at 160—170° for 5 hours. The product was worked up in the usual way, the crude *p*-toluenesulphon-γ-hydroxypropylamide (II; R = OH) being obtained as a viscous liquid. It was converted directly into the chloro-compound by treatment with thionyl chloride (119 g.) and pyridine (39·5 g.). The crude p-*toluenesulphon*-γ-*chloropropylamide* was freed from oily impurities by pressing on a porous plate, and then crystallised from benzene–light petroleum; yield 28 g., m. p. 53° (Found: Cl, 14·5. $C_{10}H_{14}O_2NSCl$ requires Cl, 14·34%). This compound (22 g.) was mixed with ethylenediamine (6 g.) and ethyl alcohol (50 c.c.) and boiled under reflux for 12 hours. The product was worked up in the usual way and gave the *dihydrochlorides* of (a) *N*-(γ-*p*-toluenesulphonamidopropyl)-ethylenediamine (III; *n* = 3, *m* = 2) (8·5 g.) and (b) *NN*′-bis-(γ-*p*-toluenesulphonamidopropyl)-ethylenediamine (IV; *n* = 3, *m* = 2) (5 g.). The former was readily soluble in water, and crystallised from ethyl alcohol, m. p. 202° (Found: Cl, 20·3. $C_{12}H_{21}O_2N_3S,2HCl$ *requires* Cl, 20·6%); the latter was very sparingly soluble in cold water, slightly soluble in hot water (Found: Cl, 12·34. $C_{22}H_{34}O_4N_4S_2,2HCl$ requires Cl, 12·6%).

The Action of Trimethylenediamine on p-*Toluenesulphon*-β-*chloroethylamide*.—The sulphonamide (36 g.), trimethylenediamine (11·5 g.), and ethyl alcohol (50 c.c.) were boiled under reflux for 8 hours. The product, worked up in the usual way, gave a hydrochloride, m. p. 205°, readily soluble in water and hot alcohol, which appeared to be the *trihydrochloride* of (III; *n* = 2, *m* = 3) (Found: Cl, 27·3, 28·9, 28·8. $C_{12}H_{21}O_2N_3S,3HCl$ requires Cl, 27·9%). The *dihydrochloride* of *NN*′-bis-(β-*p*-toluenesulphonamidoethyl)trimethylenediamine (IV; *n* = 2, *m* = 3) was very sparingly soluble in cold water; m. p. 215° (Found: Cl, 12·7. $C_{21}H_{32}O_4N_4S_2,2HCl$ requires Cl, 13·1%).

NN′-*Di*-p-*toluenesulphonyl*-NN′-*bis*-(β-*hydroxyethyl*)*ethylenediamine* (V; R = OH).—Di-*p*-toluenesulphonylethylenediamine (184 g.) was added to a solution of sodium (2·3 g.) in ethyl alcohol (200 c.c.) and benzene (200 c.c.), and ethylene oxide (112 g.) added. The mixture was heated in an autoclave for 10 hours at 100—110°. The solvent was distilled off, and the residue extracted with 10% sodium hydroxide. The insoluble residue, crystallised from aqueous alcohol, afforded the *compound* (V; R = OH), m. p. 144° (97 g.) (Found: S, 14·0, 14·4; N, 6.38. $C_{20}H_{28}O_6N_2S_2$ requires S, 14·0; N, 6·14%). [The alkali-soluble product was used later (see p. 1471).] The use of ethylene chlorohydrin instead of the oxide gave lower yields.

The compound (V; R = OH) (228 g.) was mixed with pyridine (79 g.) and carbon tetrachloride (350 c.c.), and thionyl chloride (148 g.) added to the cooled mixture (5—10°). Next day, the temperature was slowly raised to 90° to complete the reaction, and the product worked up in the usual way (crude yield, 215 g.). *NN'-Di-*p*-toluenesulphonyl-NN'-bis-(β-chloroethyl)-ethylenediamine* (V; R = Cl) crystallised from benzene–light petroleum; m. p. 145° (Found : Cl, 14·0. $C_{20}H_{26}O_4N_2Cl_2S_2$ requires Cl, 14·4%).

Action of Alcoholic Ammonia on (V; R = Cl).—The chloro-compound (30 g.) was heated in an autoclave with ethyl-alcoholic ammonia (6*N*, 450 c.c.) for 7 hours at 100—120°. The cooled solution was filtered, and the alcohol distilled off. The crude bases were extracted with cold (A) and then with hot (B) dilute hydrochloric acid. From (B) the hydrochloride of (VII) (5·1 g.) crystallised on cooling. The mother-liquors from (B) and the solution (A) were mixed and basified, giving (V; R = NH_2) (15·9 g.). The *dihydrochloride* of *NN'-di-*p*-toluenesulphonyl-NN'-bis-(β-aminoethyl)ethylenediamine* (V; R = NH_2) readily crystallised from alcoholic hydrochloric acid; m. p. 243° (Found : Cl, 13·45. $C_{20}H_{30}O_4N_4S_2$,2HCl requires Cl, 13·47%). The free *base* was insoluble in water, but crystallised from aqueous alcohol; m. p. 134° (Found : S, 13·6. $C_{20}H_{30}O_4N_4S_2$ requires S, 14·1%). The *hydrochloride* of *1 : 4-di-*p*-toluenesulphonyl-1 : 4 : 7-triaza*cyclo*nonane* (VII) readily crystallised from hot water; m. p. 289° (Found : Cl, 7·25, 7·35. $C_{20}H_{27}O_4N_3S_2$,HCl requires Cl, 7·49%). The free *base*, crystallised from alcohol, had m. p. 218° [Found : *M* (Rast), 421; *M* (ebullioscopic in acetone), 438. $C_{20}H_{27}O_4N_3S_2$ requires *M*, 437]. A third hydrochloride was isolated but is still under examination.

The Tetrahydrochloride of NN'-Bis-(β-aminoethyl)ethylenediamine (VIII).—The compound (V; R = NH_2) was hydrolysed by heating with concentrated sulphuric acid (105 g.) and water (56 c.c.) under reflux in an oil-bath at 160—170° for 10 hours. The product was basified with concentrated sodium hydroxide, and steam-distilled from an oil-bath at 180—190°. The distillate was acidified with hydrochloric acid and evaporated to dryness. The tetrahydrochloride (25 g.) was then obtained; m. p. (from alcoholic hydrochloric acid) 265°.

*Di-*p*-toluenesulphonyl-N-β-chloroethylethylenediamine* (VI; R = Cl).—75 G. of alkali-soluble product, obtained in the preparation of (V; R=OH) (see p. 1470), were extracted with hot methyl alcohol (200 c.c.). The solution, filtered from unchanged di-*p*-toluenesulphonylethylenediamine, was distilled, and the viscous residue dried by distillation with benzene and converted into the *chloro*-compound (VI; R = Cl) by the action of thionyl chloride; the product (15 g.), crystallised from ether–light petroleum, had m. p. 111° (Found: Cl, 8·6; S, 15·1, 15·2. $C_{18}H_{23}O_4N_2ClS_2$ requires Cl, 8·24; S, 14·8%). When 2·1 g. of this compound were heated with a solution of sodium (0·12 g.) in alcohol (10 c.c.), it afforded the di-*p*-toluenesulphonyl derivative of piperazine (1·5 g.), m. p. 291° (Found : S, 16·5. Calc. for $C_{18}H_{22}O_4N_2S_2$: S, 16·25%) (see J., 1934, 1304); and this (3·8 g.) was also obtained (m. p. 291°) when 4·3 g. of (VI; R = Cl) were heated with ethylenediamine (1·2 g.) in alcohol (40 c.c.).

The Action of ββ'-Diaminodiethylamine on p*-Toluenesulphon-β-chloroethylamide.*—The trihydrochloride of the base (20·9 g.) was heated with a solution of sodium (6·9 g.) in absolute alcohol (100 c.c.), and the sodium chloride filtered off; 21 g. of the sulphonamide were added to the filtrate, and the mixture boiled under reflux for 8 hours. The solution was cooled, and the crystalline product filtered off and extracted with alcoholic hydrochloric acid; di-*p*-toluenesulphonylpiperazine remained, and from the filtrate the *trihydrochloride* of p*-toluenesulphonyl-NN'-bis-(β-aminoethyl)ethylenediamine* (IX) crystallised; m. p. above 360° (Found : Cl, 25·3. $C_{13}H_{24}O_2N_4S$,3HCl requires Cl, 26·0%).

We thank Mr. F. O'Donel and Mr. L. Kee Sim for help in this work, and the University of Rangoon for a grant in aid. Work on these and related compounds and the co-ordination compounds of the corresponding bases is proceeding.

University College, Rangoon. [*Received, June 23rd*, 1937.]

NOTE.

The Preparation of 4-Methoxy-2 : 5-toluquinone. By Julius N. Ashley.

Knoevenagel and Bückel (*Ber.*, 1901, 34, 3996) showed that the condensation of 1 : 4-benzoquinone with methyl alcohol in the presence of zinc chloride gave 2 : 5-dimethoxy-1 : 4-benzoquinone. It was thought that the use of toluquinone in this reaction might lead to the production

of 3 : 6-dimethoxy-2 : 5-toluquinone. None of this substance was found, but only 4-methoxy-2 : 5-toluquinone, which had been prepared previously by Luff, Perkin, and Robinson (J., **1910**, **97**, 1137). Toluquinone (10 g.) was added to a hot solution of anhydrous zinc chloride (12 g.) in methyl alcohol (50 c.c.) and the solution was heated under reflux for 1 hour. The hot mixture was filtered, and after standing overnight in ice, the crude quinone was filtered off and washed with a little cold methyl alcohol; it (2·5 g.) had m. p. 165—170°. Crystallisation from ethyl alcohol (charcoal) gave 2 g. of pure 4-methoxy-2 : 5-toluquinone, which formed glistening golden spangles, m. p. 172—173°, not depressed on admixture with a specimen prepared by the method of Luff *et al.* (*loc. cit.*) (Found: C, 63·3, 63·1; H, 5·2, 5·2; OMe, 20·7. Calc. for $C_8H_8O_3$: C, 63·1; H, 5·3; OMe, 20·4%).

The author thanks Professor H. Raistrick, F.R.S., for his help and advice.—London School of Hygiene and Tropical Medicine, University of London. [*Received, July 14th*, 1937.]

305. *Curare Alkaloids. Part III. Pot-curare.*

By Harold King.

The curare arrow-poisons have been frequently tried in medicine. The object of the present investigation was the isolation of the alkaloidal active principle, or other constituent alkaloids of pot-curare, in the hope that the nature of the active principle and its botanical origin might be revealed. It has been found that the specimen of pot-curare under examination contains many phenolic alkaloids, two of which, neoprotocuridine and protocuridine, have now been well characterised. They are isomeric, each with the formula $C_{36}H_{38}O_6N_2$, and on exhaustive methylation give isomeric *O*-methyl methiodides $C_{40}H_{48}O_6N_2I_2$. Neoprotocuridine has been identified as an internally compensated form of *iso*chondrodendrine, an alkaloid of *Radix Pareiræ bravæ* originating from *Chondrodendron tomentosum* R. and P. This establishes a close relationship between the alkaloids of pot-curare and those of tube-curare. Both are based on the fusion of two polyphenolic benzyl*iso*quinoline nuclei by ether linkages. The presence of other alkaloids in pot-curare has been established by complete methylation. The active principle has been isolated as an amorphous phenolic quaternary iodide of high paralysing activity. The botanical origin is discussed in terms of the observations of explorers and botanists and the conclusion is reached that the alkaloids of this specimen of pot-curare originated from an Amazonian plant of the N.O. *Menispermaceæ* without the addition of any *Strychnos* species.

Pot-curare is the name given to the South American arrow-poisons put up in earthenware pots. These containers are of various sizes and may be unglazed, glazed or ornamented with paint; they are characteristic of the curare prepared by the Indian tribes who dwell on the borders of Brazil, Peru, and Ecuador, round the waters of the Upper Amazon.

Although curare has been the subject of chemical enquiry for over a hundred years, there appear to be only two clear records of the examination of curare from pots. In 1862 Buchner (*Arch. Pharm.*, **160**, 19) examined a pot-curare brought by the German botanist and explorer von Martius from the Upper Amazon. He was unable to crystallise the active principle, but found that it was bitter, alcohol-soluble, and gave a colour reaction not unlike that of strychnine. In the last few years of the 19th century, Boehm (*Abhandl. Kgl. sächs. Ges. Wiss.*, 1897, **24**, 22) brought order into the curare field by showing that the type of container was in general diagnostic of the type of curare contained therein. From various sources he collected a number of pots of curare which yielded 250 g. of crude drug but of widely differing physiological activity. This material was only sufficient to give Boehm a general orientation of the problem of pot-curare and to determine the method by which, in his opinion, the material should be worked up. Pot-curare was found to differ chemically from calabash- or gourd-curare in that an aqueous extract of the former gave a voluminous precipitate with metaphosphoric acid and a precipitate with ammonia. In this respect it resembled tube-curare, but unlike the latter, its examination presented great experimental difficulties. Only one specimen of pot-curare gave a " curarine," *i.e.*, a quaternary alkaloid

with intense curare activity. This amorphous alkaloid was called protocurarine; it gave a colour reaction (sulphuric acid and dichromate) reminiscent of strychnine. The non-quaternary alkaloids, however, called in general "curines," proved to be present as a class in all the specimens of pot-curare. From the non-quaternary alkaloids Boehm isolated a small quantity of two crystalline bases, protocurine, m. p. 306°, and protocuridine, m. p. 274—276°. They were characterised by their sparing solubility in organic solvents, and by forming crystalline sulphates and platinum salts. The latter were analysed for carbon, hydrogen, and platinum only, so the formulæ $C_{20}H_{23}O_3N$ and $C_{19}H_{21}O_3N$ attributed to the two alkaloids respectively were, in the absence of nitrogen analyses, only tentative. The two bases showed no characteristic colour reactions, but protocurine had a weak curare action on frogs.

Through the generosity of Sir Charles Sherrington, O.M., the author acquired two specimens of pot-curare in their original containers, which were given to him by the widow of the late Professor A. A. Kanthack. The pots probably came from the Amazon region, since Kanthack was born at Bahia, Brazil, and his father was Consul at Para at the mouth of the Amazon. The smaller of the two pots, a prior claim to which was very kindly relinquished by Professor Robert Robinson, is the subject of the present communication. It is an unglazed pot (diameter 7·5 cm., height 5 cm.) and contained about 30 g. of undisturbed pot-curare. Its curare activity was not very intense, since the paralysing dose (see below) was about 27 mg. per kg. of frog. Lapicque and Veil (*Compt. rend. Soc. Biol.*, 1928, **99**, 488) examined two pot-curares and found paralysing doses of 10 and 12 mg. per kg. of frog, whilst Santesson (*Acta Med. Skand.*, 1931, **75**, 7; *Skand. Arch. Physiol.*, 1936, **74**, 142) recorded two pot-curares of the same order of activity. The larger of the two pots presented by Sir Charles Sherrington contained a pot-curare far more active than any of these, as the paralysing dose was 1 mg. per kg. of frog. It has not yet been subjected to chemical investigation.

Preliminary experiments showed that in pot-curare one was dealing with a difficult alkaloidal mixture of unusual properties. By applying the methods which the author has found successful in the examination of tube- and calabash-curare and of many natural barks, it was found that pot-curare contained a mixture of many alkaloids, entirely phenolic, which, owing to the insolubility of the bulk of them, could not be taken up in chloroform or ether. This rendered the quantitative separation of quaternary from non-quaternary alkaloids impossible. In addition, saponin-like substances were present which gave rise to stable emulsions and to solutions which foamed intensely.

The method finally adopted was, in brief, to extract all soluble material by means of 1% tartaric acid solution at 100°, to precipitate complex non-alkaloidal impurities and tartaric acid with basic lead acetate, and then to precipitate the main bulk of non-quaternary alkaloids from concentrated solution with saturated sodium bicarbonate solution. The "non-quaternary" bases so obtained constituted 38% of the original curare, whilst the so-called "quaternary fraction" contained another 12% of alkaloidal bases. The original pot-curare thus contained half its weight of alkaloidal bases.

As the kernel of interest in pot-curare lies in its paralysing principle, all chemical operations have been followed by a determination of the paralysing dose on frogs under the standard conditions later defined (p. 1477). Using this frog test, it was found that the non-quaternary bases showed a weak curare action, but most of the activity was in the "quaternary fraction;" at the same time, some loss of activity was apt to occur through adsorption on precipitates and to be non-recoverable by hot solvents.

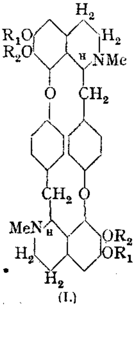
On submitting the amorphous non-quaternary fraction of the dried bases to continuous ether extraction for many weeks, a partly crystalline mixture of bases separated in the ethereal extract, which on solution in *N*-sodium hydroxide slowly deposited the crystalline sodium salt of an alkaloid, for which the name *neoprotocuridine* is proposed. By saturating the alkaline mother-liquor with carbon dioxide in the presence of chloroform, the whole of the residual phenolic bases was transferred to chloroform. On concentration of this solvent, a mixture of sparingly soluble crystalline alkaloids was obtained which, by crystallisation as the hydrochlorides, could be separated almost completely into the sparingly soluble *dihydrochloride* of neoprotocuridine and the much more readily soluble hydrochloride

of the alkaloid protocuridine discovered by Boehm. When pure neoprotocuridine base was liberated from a solution of its hydrochloride it could not be extracted by chloroform, but it slowly crystallised from the aqueous phase and could then be recrystallised from water. It had m. p. 232° and formed a well-crystallised sulphate, which, being readily water-soluble, was suitable for the determination of the specific rotation. It proved to be optically inactive. The most characteristic reaction of neoprotocuridine was its behaviour towards nitric acid. A crystalline nitrate was formed in very high dilution, but nitric acid solutions of the base could not be heated, since rapid oxidation of the alkaloidal base occurred even at 75°. Neoprotocuridine had a weak curare action.

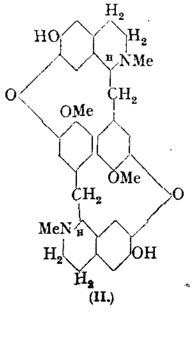
On the basis of the micro-analysis of neoprotocuridine, its hydrochloride, and its methylation product *O-methylneoprotocuridine methiodide*, there is little doubt that neoprotocuridine has the formula $C_{36}H_{38}O_6N_2,8H_2O$. The dihydrochloride is $C_{36}H_{38}O_6N_2,2HCl$, 6 or 7 H_2O, whilst methylneoprotocuridine methiodide has the formula $C_{40}H_{48}O_6N_2I_2$. The parent base neoprotocuridine has two phenolic groups and two methoxy-groups, the two former becoming methylated in methylneoprotocuridine methiodide which is no longer phenolic. The two remaining oxygen atoms are probably present as ether linkages.

Protocuridine hydrochloride has the formula $C_{36}H_{38}O_6N_2,2HCl,6H_2O$, and on complete methylation gave crystalline *O-methylprotocuridine methiodide* $C_{40}H_{48}O_6N_2I_2$ containing 4 methoxy-groups. The parent base protocuridine was obtained by Boehm as a crystalline powder, m. p. 280°, which was insoluble in all solvents. It has now been found that it can be crystallised from aqueous pyridine and then melts at 295°. A satisfactory analysis of the base was not obtained, since pyridine cannot be completely removed, a property also observed by Scholtz for the phenolic alkaloid *iso*bebeeridine (*Arch. Pharm.*, 1915, **253**, 622). The most characteristic reaction of protocuridine is the Millon reaction; this is not shown by neoprotocuridine. Furthermore, protocuridine hydrochloride, unlike neoprotocuridine, is optically active, $[\alpha]_{5461}$ + 7·6°.

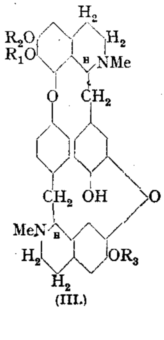
Protocuridine and neoprotocuridine are therefore two diphenolic isomeric bases of the formula $C_{36}H_{38}O_6N_2$, and on complete methylation give two different *O*-methyl methiodides, $C_{40}H_{48}O_6N_2I_2$. It is significant that the latter formula is the same as that found by the author for *O*-methyltubocurarine iodide (J., 1935, 1381), the *O*-methylation product of the active principle of tubocurare, whilst the formulæ for the parent bases show that they are isomeric with bebeerine, *iso*bebeerine (chondrodendrine, *iso*chondrodendrine), and other allied substances. The unusual properties, moreover, of protocuridine and neoprotocuridine necessitate a high molecular weight. The author is tempted to suggest that these two bases are, in fact, two further members of the bisbenzyl*iso*quinoline group of alkaloids formed by fusion of two norcoclaurine units (King, *Ann. Reports*, 1933, **30**, 242; Kondo and Tomita, *Arch. Pharm.*, 1936, **274**, 65). Since neoprotocuridine is optically inactive, the most probable constitution (if it is not a racemate) is either (I) or (II), both of which have centrosymmetrical forms.



(I.)



(II.)



(III.)

In (I) if $R_1 = H$ then $R_2 = Me$ or *vice versa*. In (II) an alternative arrangement of methoxyl and phenolic groups is not possible, since neoprotocuridine does not give a Millon reaction. In structures of these types this colour reaction seems to be shown typically only by phenolic groups in the positions occupied by the methoxy-groups in the benzyl radicals in formula (II) (see Experimental). In passing, it may be mentioned that bebeerine and tubocurarine chloride show the Millon reaction, an observation which will be of service in determining the still-unknown relative orientation of phenolic and methoxyl groups in these alkaloids. For neoprotocuridine, (I) is the more probable structure; on this basis neoprotocuridine should be a stereoisomeride of *iso*bebeerine (*iso*chondrodendrine) and both on complete methylation and Hofmann degradation should give the same optically inactive methine. On putting this assumption to the test, it was found that neoprotocuridine gave a crystalline methine or mixture of methines which on further methylation gave a methylneoprotocuridinemethine methiodide, unmelted at 320° and indistinguishable from inactive α-methyl*iso*chondrodendrinemethine methiodide, prepared from a specimen of inactive α-methyl*iso*chondrodendrinemethine kindly supplied by Professor Faltis of Vienna. Comparison of the two was not possible by the melting points but was facilitated by the observation that both give a cherry-red colour in sulphuric acid which changes on warming into an indigo-blue. This reaction appears to be highly specific, since it is not given by the isomeric optically active β-methyl*iso*chondrodendrinemethine methiodide or by any of the four isomeric methine methiodides obtained from tubocurarine or bebeerine (King, J., 1935, 1381). Neoprotocuridine must therefore have the structure shown in (I), where R_1 and R_2 are hydroxyl and methoxyl respectively or *vice versa*.

Since protocuridine is optically active and gives a typical Millon reaction, it cannot have any structure based on (I). A structure based on (II) is only possible when there is an interchange of one or both of the methoxyl groups in the benzyl radicals with the phenolic groups in the *iso*quinoline nuclei. If both central groups are phenolic, then the non-centrosymmetrical stereoisomeride must be chosen so as to confer optical activity. The possibility seems to be excluded that protocuridine might be based on a hybrid between (I) and (II) such as (III) where one of the radicals R_1, R_2, R_3 is hydrogen and the other two methyls. This is the nuclear structure of bebeerine and tubocurarine chloride, and completely methylated protocuridine is different from the only two diastereoisomerides *O*-methylbebeerine methiodide and *O*-methyltubocurarine iodide which are possible for this structure, unless indeed an obstacle effect of the central benzene nuclei is playing a part in giving rise to an increased number of stereoisomerides (cf. Faltis, Wrann, and Kühas, *Annalen*, **1932**, **497**, 69).

We turn now to the so-called "quaternary fraction," which showed the more intense curare action. This fraction, after removal of non-basic material by phosphotungstic acid precipitation, was crystallised as chloride, and readily gave sparingly soluble neoprotocuridine hydrochloride, identical with the salt obtained from the non-quaternary fraction. After removal of this salt and suitable concentration, the "quaternary fraction" was found to be precipitable by saturated sodium bicarbonate solution to the extent of 50%. The precipitate was, however, water-soluble, and consisted either of a mixture of phenolic betaines or of complex alkaloidal salts salted out by the bicarbonate. The precipitate had a paralysing dose of about 15 mg. per kg. of frog and has not been examined further. The non-precipitable "quaternary" alkaloids, having approximately twice the activity, were submitted to fractional precipitation with mercuric chloride, 11 fractions being collected. When assayed by the frog test, the activity was found to be fairly uniformly distributed and to be completely precipitable by mercuric chloride. Fraction 9 (80 mg.) had the highest activity, the paralysing dose being 4 mg. per kg. of frog. It was fractionally precipitated from methyl-alcoholic solution by ether, but in none of the six fractions collected was there any outstanding concentration of activity. These six fractions were recombined and precipitated in concentrated aqueous solution by addition of solid sodium bicarbonate; the precipitate had an activity of 10 mg. per kg. The mother-liquor was neutralised with hydriodic acid, and deposited an amorphous iodide (33·5 mg.), with a paralysing dose of 1·5 mg. per kg. of frog, *i.e.*, one-third the activity of tubocurarine chloride. This is the most active material obtained in this investigation. This iodide is phenolic and gives a

Millon reaction, but the proof that the iodide is that of a quaternary base has not been established beyond doubt. The product does not, however, show the strychnine-like colour reaction with dichromate and sulphuric acid, and it can have no connection with the protocurarine of Boehm.

All attempts to crystallise any of the fractions from the mercury precipitation of the main "quaternary" fraction with various acids failed, but that a mixture of alkaloids was present was shown by exhaustive methylation. Thus, methylation of fraction 8 with methyl iodide and methyl-alcoholic potash gave a very sparingly soluble microcrystalline alkaloidal *methiodide A*, of the unusual empirical composition $C_{20}H_{25}O_8NI_2$. It was almost insoluble in boiling organic solvents, and in boiling water its solubility was less than 1 part in 5000.

Similarly, by methylation of a combination of 7 other fractions from the mercury precipitations, a much more soluble alkaloidal *methiodide B* has been obtained, crystallising in fine needles, m. p. 318°. In crystalline properties and m. p. it agreed with methylprotocuraridine methiodide, but identity cannot at present be assumed on account of the analytical results. In addition, a minute quantity of a very sparingly soluble alkaloidal methiodide C has been obtained, unmelted at 295° and differing from any previously described.

The Botanical Origin of Pot-curare.

On the evidence of explorers and botanists, it is certain that pot-curare is made by Indian tribes of the Upper Amazon in Brazil. De la Condamine (*Hist. Acad. Sci.*, 1745, Paris 1749; *Mém.*, 489) reported that the arrow poison prepared by the Ticuna Indians was the best obtainable along the whole length of the Amazon, and that the Ticunas used the juice of many plants, especially lianes. von Martius (*Buchner's Repert. Pharm.*, 1830, **36**, 337) saw the preparation of pot-curare (urari) by the Juris on the Rio Yupurá in the Upper Amazon, and identified the chief plant used as *Rouhamon guianensis* Aubl. [now called *Strychnos guianensis* (Aubl.) Baill.]. In addition, among other plants used, there was a hitherto undescribed species, *Cocculus Imene* Mart. [= *Abuta Imene* (Mart.) Eichl.], which was probably replaced occasionally by *Cocculus grandifolius* Mart. von Spix, who accompanied von Martius on his travels, brought back a liane which was used by the Ticuna Indians and this was considered to be probably a *Cocculus* by von Martius, who called it *Cocculus amazonum*. Some years later, de Castelnau and the botanist Weddell (*Expédition dans Le Brasil et Le Perou*, *1851*, **5**, *21*) also saw curare prepared by the Ticuna Indians and neighbouring tribes. Weddell identified the plants used and named them *Strychnos Castelnaei* Wedd. (= *St. Castelnaeana* Baill.) and *Cocculus toxicoferus* * Wedd. They noticed that the quantity of the *Cocculus* used exceeded that of the *Strychnos*, since the former was a commoner plant. The explorer Jobert (*Compt. rend.*, 1878, **86**, 121; 1879, **89**, 646) speaks frequently of the adulteration of curare, and mentions that the Pebas prepared a curare which contained little or no *Strychnos* ingredients, but mainly a plant of the N.O. *Menispermaceæ*. The botanist Schwacke (*Jahrb. Kgl. bot. Gart. bot. Mus.*, Berlin, 1881—4, III, 220), who accompanied Jobert and assisted in the preparation of Ticuna curare, describes two of the ingredients as *Strychnos Castelnaei* Wedd. and *Anomospermum grandifolium* Eichl. [now known as *Elissarrhena grandifolia* (Eichl.) Diels].

The last-named species was examined by de Lacerda (*Arch. Mus. Nac.*, Rio de Janeiro, 1901, **11**, 163) who found that a crude extract had a true curare action. Unfortunately, no quantitative data are given. de Lacerda made the suggestion that the *Cocculus amazonum* of von Martius might be the same species as *Anomospermum grandifolium* of Eichler. Cl. Bernard, however, made a decoction of *Cocculus amazonum* and failed to find a curare action. de Lacerda's general conclusion was that the principal plant used in the preparation of pot-curare is a *Menisperm* and not a *Strychnos*.

* The exact identity of *Cocculus toxicoferus* and *amazonum* is unknown. The genus is uncertain owing to lack of flowers and fruit for identification, but there is no doubt about their inclusion in the N.O. *Menispermaceæ*. Maheu (Rech. Anatom. sur les Menispermacées, *J. Bot.*, Paris, 1902, **16**, 369) was of the opinion that *Cocculus toxicoferus* of Weddell is not a *Cocculus* but should be put into the monotypic genus *Strychnopsis* of Baillon endemic in Madagascar.

The French explorer Crevaux (*Compt. rend.*, 1879, **89**, 1023) brought back all the plants used on the Upper Amazon in the preparation of curare; from *Strychnos Castelnaei* Wedd. he prepared a curare ten times as strong as the Indian preparation. Rodriques ("Curare," Bruxelles, 1903), however, was of the opinion that curare made from plants of the N.O. *Menispermaceæ* (this includes the sub-families *Cocculus*, *Anomospermum*, *Chondrodendron*, *Abuta*, etc.) was destined for commerce or exchange with other tribes.

From the foregoing historical survey there are strong indications that the essential ingredients of pot-curare are prepared either from a *Strychnos* species with the addition of a *Menisperm* or from a *Menisperm* alone. The small pot of pot-curare which is the subject of this communication clearly belongs to the latter category. All the alkaloids are phenolic, and none gives a colour reaction reminiscent of strychnine, whilst the composition and characters of the crystalline alkaloids neoprotocuridine and protocuridine and their formulation as bisnorcoclaurine alkaloids are in agreement with their origin from a *Menisperm*. The identification of neoprotocuridine as an internally compensated centro-symmetrical form of *iso*chondrodendrine brings this type of pot-curare into close relationship with tube-curare which is made on the upper waters of the Amazon in Peru (River Ucayali district) and contains two closely related alkaloids, *l*-curine (= *l*-bebeerine or α-chondrodendrine) and *d*-tubocurarine chloride (King, *loc. cit.*). The latter had an activity of 0·5 mg. per kg. of frog, *i.e.*, about three times that of the amorphous iodide isolated in this investigation. The possibility that this active principle (or principles) contains tubocurarine is not excluded, but in any case the properties of the most active fraction are consistent with its being a quaternary alkaloid derived from a partly methylated bisnorcoclaurine base. It is noteworthy that the bisnorcoclaurine alkaloids of the S. American Menisperms are based, so far as is at present known, exclusively on a centro-symmetrical juxtaposition of two benzyl*iso*quinolines, whereas the Asiatic Menisperms have only yielded bisnorcoclaurine alkaloids based on a plano-symmetrical juxtaposition of benzyl*iso*quinolines.

The evidence of the botanist Schwacke (*loc. cit.*) that two of the species used by the Ticuna Indians are *Strychnos Castelnaei* Wedd. and *Anomospermum grandifolium* Eichl. is corroborated by de Lacerda's preparation of an active extract with a true curare action from *Anomospermum grandifolium* Eichl. and by Crevaux's preparation of a strong curare from *St. Castelnaei* Wedd. de Lacerda's suggestion, however, of possible identity of *Cocculus amazonum* Mart. with *Anomospermum grandifolium* Eichl. is not supported by Cl. Bernard's experimental results. It is therefore clearly desirable that chemical examination of the Menisperm, *Anomospermum grandifolium* Eichl., should be undertaken, for this may be the key to the phenolic alkaloids of pot-curare.

In conclusion it is necessary to refer to the two *Strychnos* species, *St. guianensis* (Aubl.) Baill. and *St. Castelnaei* Wedd., which have been identified as being used in the preparation of some specimens of pot-curare. Through the valuable co-operation of Mr. B. N. Wood, the Curator of Forests, British Guiana, and the Senior Forestry Officer, Mr. T. A. W. Davis, I have been able to examine the bark of a liane which was identified by Mr. N. Y. Sandwith of the Royal Botanic Gardens, Kew, as "near *St. guianensis* (Aubl.) Baill. and possibly a form or variety." A concentrated extract of this bark was devoid of curare action on frogs and contained little or no alkaloid. This receives support from Robert Schomburgk's statement ("Reisen in Guiana und am Orinoco," 1835—39, Leipzig, 1841, 94) that the Indian tribes who make curare from *St. guianensis* Aubl. prefer that made from *St. toxifera* Schomb. as being more active. Again, through the kindness of Mr. Gruber and Dr. R. T. Major, of the firm of Merck and Co. Inc. of Rahway, N.J., I was able to examine a small quantity of the bark of *St. Castelnaei* Wedd. This contained about 0·2% of amorphous non-quaternary alkaloid and a like quantity of amorphous quaternary alkaloid. The latter gave a strychinne-like colour reaction with dichromate and sulphuric acid and had a strong curare action (1·5 mg. per kg. of frog). The alkaloids were non-phenolic and bore no resemblance to those encountered in this investigation on pot-curare.

EXPERIMENTAL.

The Frog Test for Curare.—For the determination of curare activity it is essential to have a quick and reliable roughly quantitative test. Professor J. H. Gaddum, who as a former member

of our staff carried out the preliminary tests on curare, defined the paralysing dose for frogs as that quantity of curare which paralyses the righting reflex within 15 minutes, as shown by the inability of the animal when laid on its back to recover its normal posture within 1 minute, the volume of solution injected into the ventral lymph sac being 0·02 c.c. per g. of frog. The true curare nature of the paralysis was frequently checked by an observation of the effect of electrical stimulation of the exposed sciatic nerve and gastrocnemius muscle of the pithed animal. The later tests were carried out by Dr. G. L. Brown and by Miss W. I. Strangeways, and I desire to acknowledge the cordial co-operation of these three workers, without whose aid the results of the investigation could not have been attained.

Pot-curare.—25 G. of pot-curare were heated for a short time with 1% tartaric acid solution (750 c.c.) and sufficient 50% solution (5 c.c.) to make the solution faintly acid to Congo-red paper. After filtration, the undissolved solid was re-extracted with a further 100 c.c. of 1% tartaric acid. The combined filtrates (920 c.c.) were precipitated with basic lead acetate solution (200 c.c.), the precipitate removed and washed. The precipitate and the filtrate A were separately decomposed with hydrogen sulphide. The aqueous filtrate obtained on decomposing the lead precipitate was devoid of activity on the frog and was discarded. The original extract (920 c.c.) had an activity corresponding to 27 mg. of original drug per kg. of frog. An earlier assay on a separate preparation gave 29 mg. per kg. of frog.

The filtrate A was concentrated and treated at 0° with saturated sodium bicarbonate solution (170 c.c.) so long as a precipitate was formed. After 12 hours' keeping at 0° the precipitate B was collected; yield 8·65 g. The bicarbonate-alkaline filtrate was extracted, once each, with ether and chloroform, further extraction being impossible owing to the extremely difficult emulsions which were formed and which could only be temporarily resolved by filtration through kieselguhr. The chloroform and ethereal extracts were evaporated; the residue was dissolved in *N*-hydrochloric acid which had been used for extraction of alkaloidal bases from the kieselguhr, and after concentration to a small volume was precipitated by addition of solid sodium bicarbonate. The precipitated base (1·0 g.) was added to the main bulk of non-quaternary alkaloids, B. The curare activity of this non-quaternary fraction was relatively weak, 192 mg. per kg. of frog.

Examination of Non-quaternary Fraction B.

The crude dried bases, 9·65 g., were submitted to continuous extraction (Soxhlet) with dry ether for many weeks. As extraction proceeded, partly crystalline bases separated in the ethereal extract. The extraction flask was changed at long intervals, the total solid obtained from the ethereal extracts being 4·85 g. The unextracted alkaloids, 4·8 g., have been set aside for future examination.

After many preliminary experiments the following method gave satisfactory results for isolating two crystalline alkaloids from the ether-soluble bases. A portion of these bases, 850 mg., was dissolved in *N*-sodium hydroxide (7·5 c.c.) and kept at 0° for 36 hours. A crop of microscopic short needles of the sodium salt of neoprotocuridine (89·7 mg.) which separated was collected and washed with *N*-sodium hydroxide. The filtrate was saturated with carbon dioxide in the presence of a liberal quantity of chloroform, and the alkaloids completely removed by 6 extractions. The combined chloroform extract was concentrated to a small volume and readily deposited small plates as the solution boiled down. This crystalline mixture of protocuridine and neoprotocuridine (102 mg.) had m. p. 284°. It apparently contained chloroform of crystallisation, since it rapidly lost over 10% in weight when exposed to the air for a few hours. The remaining alkaloids not crystallisable as a sodium salt or from chloroform have been set aside for future examination.

Sodium neoprotocuridine (143 mg.) dissolved in boiling 0·25*N*-hydrochloric acid (35 c.c.) deposited on keeping a microcrystalline powder (91 mg.) of neoprotocuridine hydrochloride, unmelted at 310°, giving no Millon reaction but yielding a characteristic nitrate in high dilutions. If the hydrochloride is dissolved in a little hot water, addition of 2*N*-sodium hydroxide solution soon reproduces sodium neoprotocuridine in microscopic plates. Fuller details of neoprotocuridine are given under the section dealing with the "quaternary fraction."

Separation of Neoprotocuridine and Protocuridine.—The amount of these bases available from the chloroform crystallisation experiment was 506 mg. This was dissolved in 0·5*N*-hydrochloric acid and fractionally crystallised. Neoprotocuridine hydrochloride, being very sparingly soluble and separating as a rule as a microcrystalline powder, was readily obtained, and from the mother-liquors *protocuridine hydrochloride* (236 mg.), octahedra, m. p. 295° (efferv.) (Found: loss at 100° in a high vacuum, 13·1. $C_{36}H_{38}O_6N_2,2HCl,6H_2O$ requires H_2O, 13·9%. Found, for anhydrous salt: C, 64·3; H, 6·2; N, 4·5; Cl, 9·9. $C_{36}H_{38}O_6N_2,2HCl$ requires C, 64·7; H, 6·0; N,

4·2; Cl, 10·6%). The specific rotation of the anydrous salt was determined in water: $[\alpha]_{5461}^{20^\circ}$ + 7·6° (c = 0·3). *Protocuridine* base was precipitated as an amorphous solid on addition of sodium bicarbonate to a solution of the hydrochloride, but, on being kept in contact with the solution, it changed into compact tablets. It is not soluble in 2N-sodium hydroxide solution (formation of an insoluble salt) but dissolves immediately on dilution. It gives a strong Millon reaction but no coloration with ferric chloride. The only solvent from which it could be recrystallised was aqueous pyridine. The solid was dissolved in pure boiling pyridine, and water added dropwise until crystallisation set in. The base separated in irregular shaped plates, m. p. 295° (Found: loss at 100° in a high vacuum, 11·3. Found in dried material: C, 72·2; H, 6·5; N, 5·7. $C_{36}H_{38}O_6N_2,\frac{1}{2}C_5H_5N$ requires C, 73·2; H, 6·4; N, 5·5%). The sulphate crystallises readily in pointed tablets, and the platinichloride in compact anisotropic tablets. The last two salts are in substantial agreement with Boehm's observations. O-*Methylprotocuridine methiodide* was prepared by boiling protocuridine hydrochloride (76·2 mg.) with 0·5N-methyl-alcoholic potassium hydroxide (1 c.c.) and methyl iodide (0·5 c.c.), a second portion of the methylating agents being added after 30 minutes. The neutral solution deposited straw-coloured needles (81·8 mg.), which were crystallised from methyl alcohol (4 c.c.) and then separated as cream-coloured needles, m. p. 318° (decomp.) (Found: loss at 100° in a high vacuum, 2·1. Found, in dried material: C, 52·9, 52·6; H, 5·6, 5·4; N, 3·1, 3·1; I, 27·0, 27·2; MeO 12·1, 11·8. $C_{40}H_{48}O_6N_2I_2$ requires C, 53·0; H, 5·3; N, 3·1; I, 28·0; 4 MeO, 13·7%).

Examination of "Quaternary Fraction."

The mother-liquors (425 c.c.) from the sodium bicarbonate precipitation of non-quaternary bases, after neutralisation with sulphuric acid, were treated with pure sulphuric acid (21 g.), followed by 25% phosphotungstic acid solution (50 c.c.) in 5% sulphuric acid solution. The precipitate was collected, washed with 1% phosphotungstic acid solution in 5% sulphuric acid, and both the precipitate and the mother-liquor decomposed with baryta. The two filtrates were neutralised to Congo-red paper with dilute sulphuric acid, filtered from barium sulphate, and the two filtrates treated with sufficient barium chloride solution to remove sulphate ions. The filtrate from the phosphotungstic acid precipitation was devoid of any frog-paralysing principle and was rejected. The precipitate which contained all the bases, now present as soluble chlorides, was concentrated at 50° under diminished pressure and finally over sulphuric acid in a vacuum. Three crops of a microcrystalline powder (1·0 g. in all) were collected, and on crystallisation from 30 volumes of boiling water gave pure *neoprotocuridine hydrochloride* (71 g.) [Found, in two different preparations: loss at 100° in a vacuum over P_2O_5; (a) 14·4, 14·8; (b) 16·7. $C_{36}H_{38}O_6N_2,2HCl,6H_2O$ and $7H_2O$ require H_2O, 13·9 and 15·9% respectively. Found, for anhydrous salt; (a) C, 65·1, 64·9; H, 7·0, 6·9; N, 4·4, 4·3; Cl, 9·6, 9·8; MeO, 5·0, 4·7. (b) C, 64·9, 65·0; H, 6·9, 7·0; N, 4·3, 4·3; Cl, 10·3, 10·0; MeO, 4·8, 5·1. $C_{36}H_{38}O_6N_2,2HCl$ requires C, 64·8; H, 6·0; N, 4·2; Cl, 10·6; 2MeO, 9·3%]. Although this hydrochloride usually separates as a microcrystalline powder composed of microscopic prisms, it can be obtained on very slow concentration of its solution in large prisms or plates. It is unmelted at 310° and does not give the Millon reaction. In very dilute solutions it gives a crystalline nitrate on addition of dilute nitric acid, and on warming the dilute nitric acid solution to 75° oxidation rapidly takes place. The salt swells up on addition of 2N-sodium hydroxide solution, forming a sodium salt which is soluble on dilution. However, on addition of ammonium chloride, the free base is not precipitated but the hydrochloride mixed with some base. Neoprotocuridine hydrochloride had a weak curare action, 45 mg. per kg. of frog producing paralysis in 40 minutes.

Neoprotocuridine.—The hydrochloride (162 mg.) in water (15 c.c.) was treated with saturated sodium bicarbonate solution (5 c.c.). The clear solution, which went yellow, was repeatedly extracted with chloroform, which did not, however, remove the base. When the aqueous solution was kept, the *base* crystallised out; yield 98 mg. This was dissolved in boiling water (4 c.c.), and separated in diamond-shaped leaflets, m. p. 232° with slight effervescence to a red melt (Found: loss at 110° in a high vacuum, 19·5. $C_{36}H_{38}O_6N_2,8H_2O$ requires H_2O, 19·5%. Found, in dried base: C, 72·0, 71·9; H, 6·7, 6·6; N, 4·7, 4·7; MeO, 9·2. $C_{36}H_{38}O_6N_2$ requires C, 72·7; H, 6·4; N, 4·7; 2MeO, 10·4%). The sulphate crystallises readily in rhomb-shaped leaflets, and, being much more soluble than the hydrochloride, was examined polarimetrically in solution (c = 0·8); it proved to be optically inactive. O-*Methylneoprotocuridine methiodide* was readily prepared by boiling neoprotocuridine hydrochloride (98 mg.) with 0·5N-methyl-alcoholic potash (2 c.c.) and methyl iodide (1 c.c.). A sparingly soluble potassium salt was first formed, complete methylation being attained by further addition of one-half the above quantities of methylating agents. The crystalline iodide (126 mg.) which separated was crystallised from boiling water

(30 c.c.) and separated in microscopic rhombs, unmelted at 300° (Found : loss in a high vacuum at 100°, 0·4. Found, in dried salt: C, 53·1, 53·0; H, 5·6, 5·5; N, 3·2, 3·1; I, 29·5, 29·8; MeO, 13·1, 12·8. $C_{40}H_{46}O_6N_2I_2$ requires C, 53·0; H, 5·3; N, 3·1; I, 28·0; 4MeO 13·7%).

Degradation of O-*Methylneoprotocuridine Methiodide*.—The iodide (0·49 g.) was converted into the chloride in warm aqueous suspension by digestion with excess of freshly precipitated silver chloride. The filtrate, when evaporated to a syrup, crystallised as a felt of needles of the corresponding chloride. It was boiled for 1·5 hours with 20% sodium hydroxide solution (20 c.c.), and then extracted thrice with ether and then thrice with chloroform. The former on evaporation left 0·2 g. of a clear gum, which readily crystallised in needles on addition of methyl alcohol (5 c.c.). The solution was then gently boiled with methyl iodide (1 c.c.) for an hour, whereupon a crystalline methiodide rapidly separated (yield 156 mg.). The chloroform extract was more pigmented and left a gum (0·1 g.) which was similarly methylated. A crystalline methiodide (143 mg.) also separated in this case. Both crops were carefully compared with an authentic specimen of α-*O*-methyl*iso*chondrodendrinemethine methiodide. Each salt was unmelted at 320°, and each on solution in sulphuric acid gave a cherry-red colour which became a purer red on warming and indigo-blue on stronger heating. Each specimen was sparingly soluble in boiling water and on rapid cooling gave a crystalline salt of identical appearance, compact spheres or clusters in which the shape of the individual crystals was not seen, but if the solutions were allowed to crystallise slowly, well-formed crystals separated of identical appearance in each case. Comparable solutions of all three salts in dilute solution gave a crystalline nitrate of the same characteristic appearance. The sulphates and hydrochlorides were soluble salts, but perchloric acid produced an amorphous precipitate from each.

The main alkaloidal " quaternary " liquor from which neoprotocuridine hydrochloride had been obtained was treated at 0° with saturated sodium bicarbonate solution (20 c.c.) so long as a precipitate was obtained. The friable precipitate was collected at 0° and on acquiring room temperature changed to a gum which was mainly water-soluble, was weakly alkaline, and was probably a mixture of phenolic betaines. With considerable difficulty, owing to emulsion formation, it was thoroughly extracted with chloroform, which removed a further quantity of non-quaternary alkaloids (0·3 g.). The neutralised extracted liquor when evaporated to dryness gave an amorphous residue (1·34 g.), which in a dose of 20 mg. per kg. of frog paralysed in 12 minutes. It has not been examined further.

The " quaternary fraction " still not precipitated by bicarbonate, after chloroform extraction which removed 0·1 g. of bases, was neutralised, and dried; yield 1·285 g. The paralysing dose was 8 mg. per kg. of frog in 12 minutes. This fraction, in water (10 c.c.), was stirred mechanically, and fractionally precipitated with powdered mercuric chloride, ten fractions being collected. Each was freed from mercury by treatment with hydrogen sulphide, but the first 8 fractions retained colloidal mercuric sulphide with persistence. By frog tests it was found that the whole of the active material had been precipitated and was fairly uniformly distributed throughout the fractions. Fraction 9, however (79·7 mg.), was slightly more active with a paralysing dose of 4 mg. per kg. within 11 minutes. It was further fractionally precipitated from methyl-alcoholic solution by dry ether, 6 fractions of approximately the same activity being obtained from which no crystalline salts could be obtained. The six fractions were recombined in a little water, and treated with solid sodium bicarbonate so long as a precipitate was formed. The precipitate (20 mg.) had a paralysing dose of 10 mg. in 13·5 minutes. The bicarbonate mother-liquor was neutralised with hydriodic acid solution, which caused an amorphous iodide (33·5 mg.) to separate. This had a paralysing dose of 1·5 mg. per kg. of frog in 15 minutes, *i.e.*, it had about one-third of the activity of *d*-tubocurarine chloride. The amount of material was insufficient for further fractionation. The iodide did not give a strychnine-like colour reaction with bichromate and sulphuric acid. It was instantly soluble in 2*N*-sodium hydroxide solution but not in sodium bicarbonate. It gave a Millon reaction but no sparingly soluble nitrate and it was not apparently sensitive to warm dilute nitric acid. It is therefore different from Boehm's protocurarine.

O-*Methylation of Fraction* 8.—All attempts to crystallise the water-soluble chlorides from the mercury fractionation as such or with other precipitants failed. Methylation was therefore resorted to in the hope of being able to obtain crystalline derivatives, although the active principle or principles present would at the same time become methylated and be irrecoverable. Fraction 8 (120 mg.) was gently boiled in 0·5*N*-methyl-alcoholic potassium hydroxide solution with methyl iodide. A heavy, white, microcrystalline solid (114 mg.) rapidly separated, which was almost insoluble in all solvents. It was possible, however, to recrystallise it by extracting it from a sintered-glass micro-extraction thimble with a small volume of boiling methyl alcohol;

yield 80·7 mg., m. p. 260° (decomp. after browning from 238°). This *iodide A*, was a whitish-cream powder showing anisotropic spheroidal crystals under the polarising microscope (Found: loss in a high vacuum at 100°, 1·1. Found, in dried material: C, 36·6, 36·5; H, 4·0, 4·0; N, 2·2, 2·1; I, 36·5, 37·3; MeO, 9·0, 9·1. $C_{20}H_{25}O_8NI_2$ requires C, 36·3; H, 3·8; N, 2·1; I, 38·4; 2MeO, 9·4%). The extreme insolubility of this substance probably necessitates a much higher molecular weight, possibly double that indicated. The high iodine and oxygen contents are unusual but are supported by duplicate analyses.

O-Methylation of Fractions 1, 3, 4, 5, 6, 7, *and* 10 *combined*.—By exhaustive methylation of these combined fractions (535 mg.) in a similar manner to the above, there was no separation of any iodide until the solution had been concentrated. A sparingly soluble iodide C (32 mg.), unmelted at 295°, then separated in anisotropic nodules. The main bulk of material was, however, readily soluble in methyl alcohol, but could be fractionally precipitated by addition of water with separation of a succession of gums which on re-solution in methyl alcohol slowly deposited clusters of straw-coloured needles. The various crystalline fractions of similar appearance were collected and crystallised twice from methyl alcohol, the pure *iodide B*, m. p. 318° (40 mg.), separating in clusters of cream-coloured needles (Found, in salt dried at 100° in a high vacuum: C, 51·7, 51·9; H, 5·5, 5·5; N, 3·4, 3·6; I, 32·1, 32·1; MeO, 13·8, 13·7. $C_{17}H_{22}O_2NI$ requires C, 51·1; H, 5·7; N, 3·5; I, 31·8; 2MeO, 15·5%. $C_{18}H_{22}O_2NI$ requires C, 52·5; H, 5·4; N, 3·4; I, 30·9; 2MeO 15·1%). This iodide is very similar in its properties to O-methylprotocuridine methiodide. It has the same m. p. and does not depress the m. p. of the latter. It is not very soluble in hot water and gives no precipitates with metaphosphoric acid or nitric acid. Although the duplicate microanalytical figures show agreement among themselves but diverge considerably from those of O-methylprotocuridine methiodide, the very close similarity of the two salts suggests identity, and it is possible that in the " quaternary fraction " there is a new soluble phenolic quaternary chloride which on O-methylation gives O-methylprotocuridine methiodide. The final aqueous liquor from the methylation containing water-soluble quaternary salts was freed from iodide by silver chloride and then freed from inorganic salts by drying and alcohol extraction. The residual solid (89 mg.) obtained on removal of alcohol had a frog-paralysing dose of 6·9 mg. per kg. in 17 minutes.

Boehm's Metaphosphoric Acid Reaction.—Boehm found that metaphosphoric acid solution gave a precipitate with the alkaloids from pot-curare and also with curine from tube-curare. This was interpreted as showing that pot-curare contains alkaloids of the curine group. Whilst this deduction is correct, as the present communication has demonstrated, the argument is not a sound one, since metaphosphoric acid solution gives precipitates with the salts of a large number of alkaloids, *e.g.*, coclaurine, bebeerine methochloride, ergotoxine, isoemetine, brucine, and demethoxyemetine, but not with protopine or papaverine. It is essential that the metaphosphoric acid solution should be prepared from freshly ignited acid, since phosphoric acid does not give these reactions.

The Millon Reaction.—A positive reaction with the Millon reagent is readily given by phenols with one other substituent, as *e.g.*, guaiacol and the three cresols. On the introduction of another substitutent the reaction becomes more specific, for it is not given by thymol, carvacrol, α-naphthol, or *iso*vanillic acid, all of which have free positions *o*- and *p*- to the phenolic group. The reaction is, however, given by β-naphthol, vanillin, and methyl vanillate, which have at least one free *o*-position, but in which the *p*-position is occupied. When there are three substituents besides the phenolic group, the reaction is not given in the case of corybulbine, which is an *iso*quinoline alkaloid of the corydaline group with an *iso*quinoline group substituted in 6 and 7 by phenolic and methoxy-groups respectively. A positive reaction is, however, given by the bisbenzyl*iso*quinoline alkaloids, bebeerine and tubocurarine chloride, and by protocuridine but not by neoprotocuridine. From these results it seems legitimate to conclude that in a bisbenzyl*iso*quinoline alkaloid of the types shown in (I), (II), and (III), no Millon reaction would be given by (I) or (II), since the reaction with corybulbine is negative, but if either (or both) of the central methoxy-groups in (II) was made phenolic, a positive reaction would be given, since vanillin and methyl vanillate give the reaction. For similar reasons (III) would give a positive Millon reaction only if the phenolic group was in the position shown. It follows that, in tubocurarine chloride and in bebeerine which have structures based on (III), one of the phenolic groups is in the central benzyl nucleus as shown. This argument, if valid, leads to a relative orientation of phenolic and methoxyl groups in tubocurarine different from that provisionally assigned in Part I of this series (*loc. cit.*, p. 1384).

Examination of Strychnos Castelnaei *Wedd*.—The powdered bark (79 g.), percolated with 1% tartaric acid (1400 c.c.), showed a weak reaction with Tanret's reagent. The solution was

purified with basic lead acetate solution (200 c.c.), and the filtrate freed from lead and concentrated (17 c.c.). On the frog this solution had a true curare activity corresponding to 0·8 g. of original bark per kg. of frog, paralysis occurring in 8 minutes.

The alkaloidal solution was made alkaline with sodium bicarbonate (5 g.) and thoroughly extracted with chloroform. The alkaloidal bases from the latter were converted into amorphous hydrochlorides (155 mg.). These contained no phenolic bases, and did not give a strychnine-like colour reaction. The bicarbonate mother-liquor was neutralised, made up to 100 c.c., and precipitated by addition of powdered mercuric chloride (7·5 g.). The cream-coloured mercurichloride of the quaternary bases was freed from mercury, and the resulting solution of quaternary alkaloidal chlorides evaporated to dryness and extracted with absolute ethyl alcohol. The extracted chlorides (150 mg.) gave a purple colour with sulphuric acid and dichromate or ammonium vanadate. A dose of 1·5 mg. per kg. of frog paralysed in 14 minutes. It was converted into the sparingly soluble amorphous iodide, which had a paralytic dose of 2 mg. per kg. *St. Castelnaei* bark therefore contains about 0·4% of alkaloidal bases, one-half of which are non-quaternary and one-half quaternary.

Examination of St. guianensis *(Aubl.) Baill.*—The bark of this species of *Strychnos*, No. 2467 in the British Guiana Forest Department Records, when percolated with 1% tartaric acid solution, gave a very dark solution unlike that obtained from any *Strychnos* hitherto examined. The extract gave a weak Tanret reaction only in the presence of mineral acid. The substance responsible for this reaction appeared to be a complex acid removable by basic lead acetate. The concentrated original tartaric acid extract when neutralised showed no curare action on a frog within 1 hour in a dose corresponding to 20 g. of bark per kg. of frog.

NATIONAL INSTITUTE FOR MEDICAL RESEARCH, HAMPSTEAD. [*Received, June 15th, 1937.*]

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306. *Studies in the Mechanism of Flame Movement. Part IV. The Vibratory Period.*

By H. F. COWARD, F. J. HARTWELL, and E. H. M. GEORGESON.

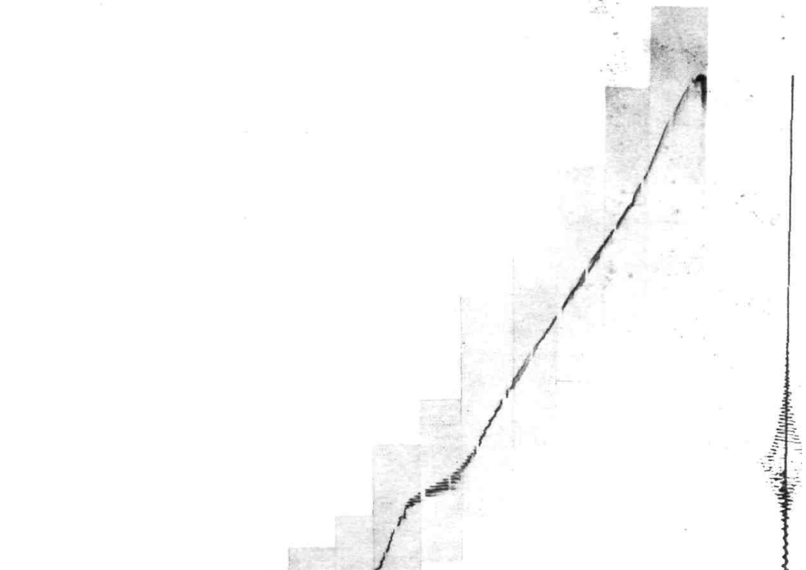
The vibratory movement during the propagation of flame in various mixtures of methane and air contained in tubes of various dimensions, the flame travelling from an open towards a closed end, has been examined. Each of the frequencies observed in tubes up to 10 metres in length corresponded with the fundamental note or with a low overtone of the whole column of gas in the tube, as calculated from Lees's formula. In a tube 32·3 metres in length the vibrations were less regular but many of them corresponded with the fundamental note.

Various means were discovered for suppressing the vibrations of such a flame, including a partial closure of the open end of the tube and a provision of gauze releases along the wall of the tube. In a certain tube of square cross-section the flame failed to vibrate, whereas in a tube of equal length and equal (but circular) cross sectional area the vibrations were large in amplitude.

MALLARD and LE CHATELIER (*Ann. Mines*, 1883, **4**, 274) obtained moving-drum photographs of the vibratory movement of flame during the explosion of the mixture $CS_2 + 6NO$ in a horizontal tube which was open at the firing end and closed at the other. With this mixture, the period and amplitude of the vibrations varied from point to point as the flame travelled along a tube; it was very rare that several consecutive vibrations had exactly the same period; and in repetition experiments the vibratory movement was never reproduced in the same manner twice. Mason and Wheeler's records of methane–air explosions (J., 1920, **117**, 36) were much more regular, and suggested to them that resonance in the column of gas governed the frequency. The present communication contains some tests of this hypothesis.

A resonating column of gas through which flame is travelling is divided by the flame-front into parts which have different acoustic properties. Lees (*Proc. Physical Soc.*, 1929, **41**, 204) has deduced the resonance frequency, n, of a column of gas, one portion of which is at a temperature T_1 and the other at a temperature T_2, for vibrations in a tube closed at

FIG. 1.



Composite photograph of explosions of 10% methane–air mixtures.

[*To face p.* **1483**.

both ends, open at both ends, or closed at one and open at the other. In the last-named circumstances, the frequency should satisfy the condition

$$(n_1/F_1) \tan p_1\pi/2 = -(n_2/F_2) \tan (p_2 - 1)\pi/2$$

in which n_1 and n_2 are the fundamental frequencies when the whole length of the column is at T_1 or T_2 respectively; F_1 and F_2 are the moduli of adiabatic elasticity for the longitudinal displacements in the column; p_1 and p_2 are nl_1/n_1L and $n(L - l_1)/n_2L$ respectively; L is the length of the tube and l_1 the distance between the junction (flame-front) and the open end of the tube.

The exact application of Lees's formula to the problem under consideration would be possible only if the hot gases were at a constant known temperature during an experiment; but this is not so, for they are rapidly losing heat to the walls of the vessel. An upper limit to their temperature may, however, be assigned on the assumption that the products lose no heat during the explosion, and a lower limit for their mean temperature may be determined by a simple experiment. The observed frequencies should then lie between those calculated from the estimated limits of temperature.

When, as in the present experiments, the tube is open at the firing end, the hot products are propelled towards the open end of the tube, but their mean speed can be shown not to exceed about 12 m./sec. and may therefore be neglected in comparison with the speed of sound in the mixture.

EXPERIMENTAL.

Methods.—Four tubes were used, three for laboratory experiments, one for field work. Their lengths and diameters were, severally: (1) 5·004 m., 10 cm.; (2) 5·07 m., 20 cm.; (3) 10·17 m., 20 cm.; and (4) 32·3 m., 30·6 cm. The first three were built of sections, each 1 m. in length. One section of each was fitted with a row of quartz windows, 0·5 cm. in width, through which the flame was photographed by a revolving-drum camera. By moving this section to successive positions along the tube, a series of photographs of repeated explosions could be obtained, and when these were joined together they formed a composite picture of the movement of flame through the whole length of the tube. Fig. 1 gives an example of this; it represents the explosion of a 10% methane–air mixture in the first tube. Somewhat similar results were obtained for explosions in the second and third tubes; a reproduction of the composite picture for the third tube is given in the Annual Report of the Safety in Mines Research Board for **1928**.

On the right-hand side of Fig. 1 is a record of the pressure changes corresponding with the flame movements in an explosion in the first tube. The record was made by a manometer attached to the closed end of the tube. At any moment during the vibratory period, the frequencies of the pressure variations were equal to those of the flame vibrations; hence for the purpose of determining frequencies the manometer could replace the camera, and one experiment could replace the 15 or 30 needed with the shorter tubes. The manometric method was therefore used alone with the largest tube.

General Review of Laboratory Results.—The original photographs, on which a time-scale had been recorded, show that the flame of a 10% methane–air explosion, travelling in a horizontal tube just over 5 m. in length, began to vibrate, at about 1·5 m. from the point of ignition, with a frequency of about 70 per sec. These vibrations reached a maximum amplitude, died away, and were followed by vibrations of frequency 33 per sec., which persisted until the flame was near the closed end of the tube, whereupon the frequency became less regular at about 70—90 per sec. (Fig. 1).

In all experiments in which comparative records were made photographically and manometrically, the measured frequencies were equal for the same position of the flame; the amplitudes recorded were usually not equal, however, for when the flame was near a node of the resonating column (as, *e.g.*, when it was near the closed end of the tube) the amplitude of its vibration was necessarily small although the amplitude of the pressure variations might be large.

Measurements of the frequencies of the chief vibrations are collected in Table I. A comparison of the first and second columns of frequency figures shows the essential agreement of the results of the manometric and the photometric measurements. A comparison of these two columns with the third shows that, in general, the frequency was increased slightly when the diameter of the tube was doubled, the length being unchanged; an effect characteristic of a resonance of the column of gas, with an allowance for somewhat less cooling in the wider tube.

TABLE I.

Frequencies of vibrations (number per sec.).

Length of tube, m. ...	5·004		5·07		10·17	10·17	10·17
Diameter of tube, cm.	10		20		20	20	20
Mixture, CH_4, %	10		10		10	7	12
Vibrations recorded by	Manometer.	Photo.	Photo.		Photo.	Photo.	Photo.
1st half metre	—	—	—	1st metre	—	—	—
2nd ,, ...	—	—	—	2nd ,,	—	—	—
3rd ,, ...	—	—	—	3rd ,,	—	—	—
4th ,, ...	69	69	71	4th ,,	35	33	33, 11
5th ,, ...	71	39, 30	71	5th ,,	32, 15	14	14
6th ,, ...	31	31	33	6th ,,	16	14	15
7th ,, ...	32	32	35	7th ,,	17	15	16
8th ,, ...	30	30	35	8th ,,	17	17	17
9th ,, ...	31	31	97	9th ,,	16, 45	42	39
10th ,, ...	70—90	70—90	87	10th ,,	(100, 70, 40)	36	37

The last three columns of figures show that, when the length of the 20 cm.-diameter tube was doubled, the results were much the same at equal fractional distances along the tubes, except that the frequencies were halved; this was so in spite of the fact that the speed of flame in the 7 and 12% methane mixtures was much less than that in the 10% mixture. The results leave little doubt that the vibrations are resonance effects.

Comparisons between Calculated and Observed Frequencies of Vibrations of Flame.—Calculation of resonance frequencies by means of Lees's formula requires a knowledge of the temperature of the hot products of combustion. This must lie well below the observed flame temperature, which, for a 10% methane–air mixture, is 1880° (Jones, Lewis, Friauf, and Perrott, *J. Amer. Chem. Soc.*, 1931, **53**, 869). A lower limit was determined by the following means: Immediately after the flame of an explosion had reached the closed end of the tube, a cover was fixed over the open end and the cooling products of combustion were allowed to draw air into the tube through a tap until the room temperature had been reached. The tap was then closed and the contents of the tube were well mixed by circulation, sampled, and analysed. The fractional partial pressure of the flame gases, including the water vapour which has condensed, is nearly equal to the ratio between the absolute temperature of the room and the absolute mean temperature of the contents of the tube at the moment of greatest expansion. The figures for the lower limit estimated in this manner are given in Table II, together with other data used for calculations with Lees's formula.

TABLE II.

Length of tube, m.	5·004	5·07
Diameter of tube, cm.	10	20
Mixture, % CH_4	10	10
Room temperature	15°	22°
Estimated lower limit of mean temperature of products	526°	750°
C_p/C_v, original mixture, room temperature	1·387	1·386
C_p/C_v, products, 1880°	1·252	1·252
C_p/C_v, products, at estimated lower limit of temperature	1·316	1·295
Speed of sound in original mixture at room temperature, m./sec.	346	350
Speed of sound in products at 1880°	901	901
Speed of sound in products at estimated lower limit of temperature	557	633
n_1	17·2	17·0
n_2 at 1880°	44·7	43·7
n_2 at estimated lower limit of temperature	27·6	30·7

It may be noted that, although the mean temperature of the products is estimated between very wide limits, *e.g.*, 750° and 1880°, the corresponding values of n_2 have a ratio, in this example, of about 0·7 : 1. The crudeness of the estimate of the mean temperature is, therefore, of less importance than might appear.

Figs. 2 and 3 contain the values of the measured frequencies of flame vibrations in the laboratory tubes. Each pair of curves represents the frequencies of vibration of the whole column of gas in the tube, calculated from the two limits ascribed to the temperature of the products of combustion; one pair for the fundamental frequency, others for the lower harmonics. There would seem to be no doubt that, in these experiments, the most intense vibrations of the flame (see Fig. 1) represent the fundamental vibrations of the gas, and that the first harmonic is represented by vibrations in both the early and the latest stages. A few small vibrations representing the second and third harmonics can be detected on the original photograph.

The incidence of vibrations seems to depend on the relative positions of the flame and of the nodes and antinodes of the lower harmonics. In Fig. 1, for example, the first observed vibrations belong to the second harmonic and occurred just before the flame reached a node. Just after the flame had passed the nodal position a well-marked series of first harmonic vibrations appeared; their amplitude rapidly increased but almost suddenly fell to zero just before the flame reached the node of the first harmonic. For a short interval some weak vibrations of the third harmonic occurred, just in front of a node. They were soon replaced by the chief phase of the vibratory period, in which for a considerable distance along the tube the flame vibrated with frequency equal to the fundamental and with an amplitude that rose to a high value. This phase was replaced by a first harmonic vibration as the flame approached the closed end of the tube.

FIG. 2.

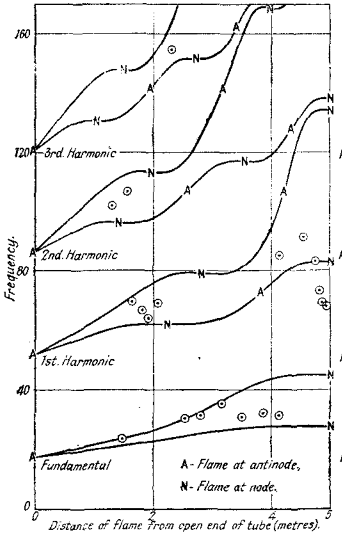
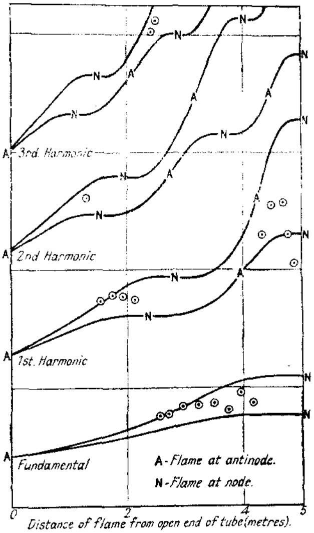


FIG. 3.



Observed [⊙] *and calculated frequencies of vibration of flame.* Fig. 2: *Tube* 5·004 *m. in length,* 10 *cm. in diameter.* *Fig.* 3: *Tube* 5·07 *m. in length,* 20 *cm. in diameter.*

In general, it may be concluded that the various phases of the vibratory period, characterised by frequencies corresponding with the fundamental and over-tones of the tubes used, tend to develop between antinode and node of one of the possible modes of resonance, their amplitudes rising to a maximum and falling away. When the flame, which provides the energy for the vibrations, is about half-way along the tube, the fundamental is developed, but at earlier and later stages of the flame the harmonics appear.

Experiments on a Larger Scale.—A tube 32·3 m. in length and 30·5 cm. in diameter, supported horizontally, was fitted with a manometer at one end, which was closed to the air. The other end was fitted with a sliding plate which was removed at the moment when the mixture in the tube was ignited there.

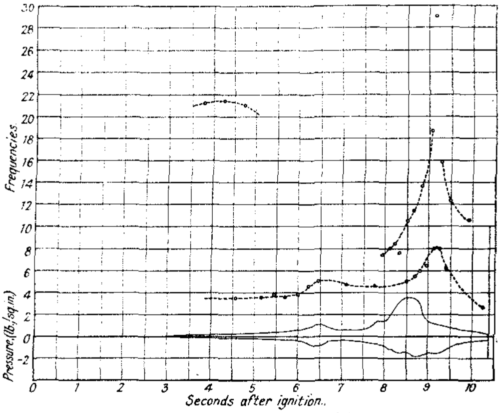
The explosions in this tube proved to be neither so regular nor so reproducible as those in the smaller tubes. In Fig. 4, which shows the results of a typical experiment, the frequencies are indicated by the points on the broken curves, the amplitudes of vibrations by the continuous

curves which envelop the record (unreproduced) of the manometer. The first vibrations observed are of about 21 frequency but small amplitude; shortly afterwards they are found superposed on a low-frequency vibration of 3·4 per sec. which rises to about 5 and later to 8 before it falls away. Between the eighth and the tenth second a higher-frequency vibration appears, superposed on the others. None of these is instrumental, for the natural period of the manometer system was 370.

The fundamental resonance frequency when the tube is full of cold gas is about 3 per sec. The lowest of the broken curves probably represents the fundamental in the whole column of gas behind and in front of the flame.

The Suppression of Vibrations of Flame.—We had observed (J., 1926, 1522) that flame vibrations in upper-limit mixtures of methane (about 14%) in air, in a tube 5 cm. in diameter, could be suppressed by a pad of cotton-wool held loosely over the open end of the tube. As there might be useful applications if the vibrations of more violent explosions could be damped in some such way, trials were made with the most explosive mixture of methane in air, first in the laboratory and then in the large tube.

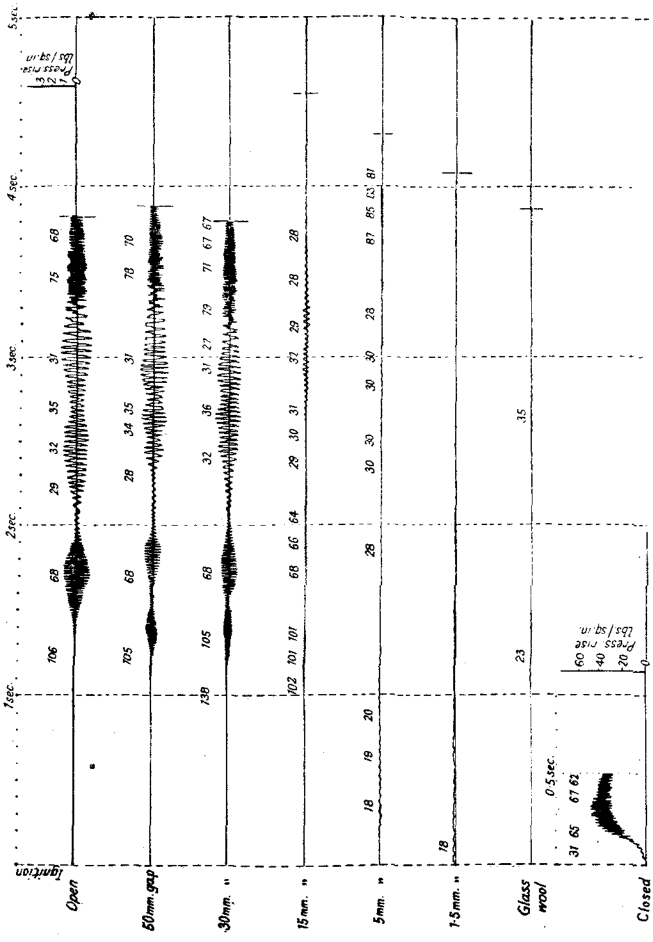
FIG. 4.



Frequencies (broken lines) and pressure variations (whole lines) of the explosion of a 10% methane–air mixture in a tube 32·3 metres in length, open at the firing end.

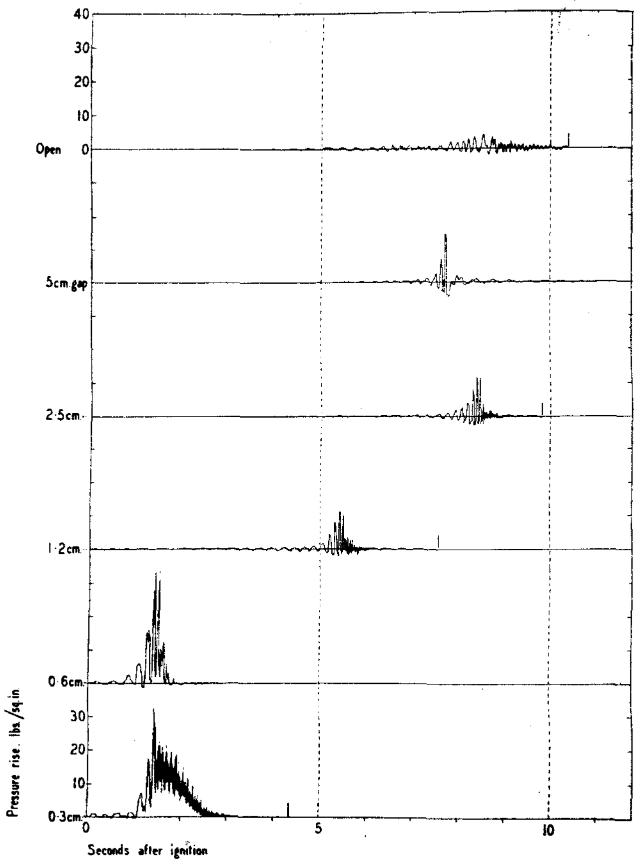
The laboratory observations are summarised in Fig. 5, which is a collection of manometer records of 10% methane–air explosions in the tube 5 m. in length, 10 cm. in diameter. The first record was obtained with the tube fully open at the firing end; it is a repetition of the experiments recorded in Fig. 1. The numbers at various points above this and the following records are frequencies of the pressure alternations at those points. The amplitudes of the pressure changes may be read on the scale to the right. A rigid metal plate was brought, in successive experiments, nearer and nearer to the firing end. The records show that when the gap between the plate and the tube was 5 cm. or 3 cm. the character of the explosion was almost the same as in the open tube. With a gap of 1·5 cm. the vibrations were almost suppressed; also with gaps of 0·5 and 0·15 cm. and with a pad of glass-wool instead of the plate. When the tube was completely closed, however, the character of the explosion was quite different; the combustion, instead of taking 4 secs., was complete in about 0·5 sec., a large positive pressure was developed, and the amplitudes of the vibrations were multiplied some ten-fold.

Observations with the largest tube (32·3 m. in length, 30·6 cm. in diameter) are summarised similarly in Fig. 6. The results were in marked contrast to those obtained in the smaller tubes. The vibrations were not suppressed when gaps of 5, 2·5, 1·2, 0·6, and 0·3 cm. were left between a



Manometric records of successive explosions of a 10% methane–air mixture in a tube 5 m. in length, 10 cm. in diameter, the aperture at the end being reduced in stages.

FIG. 6.



Manometric records of successive explosions of a 10% *methane–air mixture in a tube,* 32·3 *metres in length, the aperture at the end of the tube being reduced in stages.*

plate and the end of the tube, but with each decrease in the size of the gap the total time of explosion decreased and the violence of the vibrations increased considerably. Finally, in a repetition of the experiment with the smallest gap, the far end of the tube was shattered.

The time of arrival of the flame at the closed end of the tube is indicated in Figs. 5 and 6 by

bars. In two of the experiments of Fig. 6 the flame did not reach the end of the tube, but was self-extinguished, apparently during a violent vibration.

The experiments just described suggest that the provision of a suitable narrow gap in a flame-proof enclosure may serve not only to relieve the pressure of an explosion of firedamp within it, but also to eliminate violence due to vibrations; the violence of a firedamp explosion in a long gallery is, however, increased by reducing the size of an opening near the point of ignition in the gallery.

Miscellaneous Observations on the Suppression of Vibrations of Flame.—It may be of value to record some isolated observations on the vibrations of flame:

(1) The vibratory movement did not occur in a tube of square cross-section, 122 cm. in length and 4·4 cm. side, during the propagation of flame in a 10% methane–air mixture. A slight hum indicated weak undulations, but their amplitude was not large enough to alter the shape or speed of the flame from those of the uniform movement. Flames in the same mixtures contained in a tube of circular cross-section of the same area and of the same length began to vibrate strongly at a distance of 60 cm. from the open end. The difference may be due to a release of pressure in the corners of the square tube, into which the flame penetrates tardily.

(2) When a slit was cut in a tube, 110 cm. in length and 2·5 cm. in diameter, and the slit was covered by fine copper gauze, the propagation of flame in any methane–air mixture within the tube was almost or quite noiseless. In some experiments the tube was held horizontally in the air, the slits being below; in others the tube was surrounded by a wider tube full of the same mixture, and very little air passed through the gauze during an experiment.

(3) In a rubber tube, 73 cm. in length, 2·5 cm. internal diameter, walls 0·31 cm. thick, flame travelled through a 10% methane–air mixture with only a low purr. When the tube was fitted with a glass end-piece, 15 cm. in length, vibrations of about 5 cm. amplitude were seen. When the tube was replaced by one with walls only 0·08 cm. thick, the flame was noiseless.

Observations (2) and (3) are consistent with the interpretation of the vibratory period of flame as a resonance phenomenon, the resonating column being damped either by a release of pressure through gauzes along the walls, or by walls of flexible material.

The authors thank the Safety in Mines Research Board for permission to publish this communication.

SAFETY IN MINES RESEARCH BOARD LABORATORIES,
SHEFFIELD. [*Received, June 23rd, 1937.*]

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307. *Studies in Chemisorption on Charcoal. Part IX. The Influence of Temperature of Activation on the Sorption of Acids and Bases.*

By ALEXANDER KING.

In previous papers of this series, the fundamental effects of temperature of activation on the properties of charcoal as an adsorbent and catalyst have been reported, and the results ascribed to the formation of specific surface oxides. Previous workers have noticed that charcoals activated at high temperatures have no power of adsorbing bases but are good acid adsorbents, while activations in the neighbourhood of 400° produce samples which adsorb bases. The adsorption of a number of acids and bases on pure charcoals activated at 15 different temperatures has now been measured, and an estimate made in each case of the adsorption per unit area. It appears that the adsorption per unit area of acids increases with temperature of activation up to about 850°, while over the same temperature range base adsorption falls to zero from a considerable value. Above 850°, base adsorption reappears to a slight extent, while that of acids decreases somewhat. These variations are in agreement with the changes in other properties with temperature of activation, already studied by the author.

IN earlier parts of this series (J., 1935, 889; 1936, 1688; *Trans. Faraday Soc.*, 1934, **30**, 1094) the effect of the temperature of activation of charcoal in an atmosphere of oxygen on its adsorbent and catalytic properties has been discussed, and the fundamental variations ascribed to the existence of different surface oxides of carbon characteristic of the tem-

perature of activation. The surface of charcoals which have been oxidised in the neighbourhood of 400° is acidic, and capable of adsorbing bases, while that produced at 850° is basic and will not remove alkalis from solution. The fundamental effect of temperature of activation on the properties of charcoal eluded the earlier investigators, but the exclusion of bases by high-temperature samples, and their adsorption by charcoals activated at relatively low temperatures, was observed by a number of workers (Kruyt and de Kadt, *Kolloid-Z.*, 1929, **47**, 44; Schilow, Shatunowskaja, and Tschmutow, *Z. physikal Chem.*, 1930, **149**, 211; Kolthoff, *J. Amer. Chem. Soc.*, 1932, **54**, 4473). Although these results are, collectively, fairly comprehensive and their implication clear, it was thought useful to measure the adsorption of a number of acids and bases on a pure charcoal surface activated at a larger number of temperatures, allowance being made for the increased activity due to surface extension by the more vigorous oxidation at the higher temperatures. It should thus become possible to relate variations of acid–base adsorption with temperature of activation to those of other properties of the pure charcoal surface, described in earlier parts of this series.

Measurement has therefore been made of the adsorption of hydrochloric, acetic, and benzoic acids, of sodium and ammonium hydroxides, and of iodine on pure sugar charcoals activated by heating in moist oxygen at different temperatures. It should be noticed that the molecules chosen for adsorption were all of small dimensions, so complications due to the steric effect of ultraporosity, first observed by Landt and Bhargava (*Z. Ver. deut. Zuckerind.*, 1929, **79**, 470) and discussed also by the present author (J., 1934, 1975), would be eliminated.

The results are expressed in the table as amount of adsorption in equivalents $\times 10^{-5}$ per g. of adsorbent. In the case of hydrochloric acid a few determinations were made of the amount of chloride adsorbed, as well as those in which the difference of hydrogen-ion concentration of the solution before and after adsorption was measured. In all these cases the adsorption of the chloride ion was the same as that of the hydrogen ion, in agreement with Kolthoff (*Rec. trav. chim.*, 1927, **46**, 594), who showed that the anions and cations of inorganic acids were adsorbed to an equal extent on pure charcoal.

It is immediately obvious from the table that the adsorption of both acids and bases is fundamentally influenced by the type of surface oxide, for the samples activated in the neighbourhood of 400° show a maximum base and minimum acid adsorption, whereas maximum acid and zero base adsorption corresponds to activation at *ca.* 850°.

Adsorption of acids and bases on pure charcoal.
(equivs. $\times 10^{-5}$ per g.).

No.	Temp.	I_2.	HCl.			$CH_3 \cdot CO_2H$.		$C_6H_5 \cdot CO_2H$.		NaOH.		NH_4OH.	
1	350°	75	2·8	2·75*	*0·37*	16·2	*2·16*	50·3	*6·7*	30·2	*4·03*	56·7	*7·54*
2	380	99	0	0	*0*	18·5	*1·87*	47·5	*4·8*	153	*15·5*	180	*18·2*
3	415	166	0	0	*0*	28·2	*1·70*	69·5	*4·18*	158	*9·51*	198	*11·9*
4	420	220	0	0	*0*	36·2	*1·66*	91·0	*4·14*	175	*7·96*	199	*9·05*
5	480	221	1·9	—	*0·08*	40·2	*1·82*	94	*4·25*	105	*4·76*	139	*6·25*
6	550	247	5·9	5·9	*0·24*	71·5	*2·89*	109	*4·43*	41	*1·66*	53	*2·14*
7	650	288	13·6	—	*0·47*	90·0	*3·12*	142	*4·87*	18	*0·62*	34	*1·18*
8	700	299	15·8	—	*0·53*	96·5	*3·23*	161	*5·38*	13·3	*0·44*	25	*0·84*
9	760	551	31·5	—	*0·57*	205	*3·71*	336	*6·10*	2·0	*0·36*	31·5	*0·57*
10	810	652	43·0	—	*0·66*	265	*4·05*	482	*7·39*	0	*0*	4·5	*0·07*
11	890	571	44·6	44·5	*0·78*	228	*3·98*	426	*7·44*	10·1	*0·18*	22·7	*0·39*
12	980	436	31·5	—	*0·72*	172	*3·95*	324	*7·42*	8·2	*0·19*	18·4	*0·42*
13	1030	493	33·0	—	*0·67*	185	*3·77*	274	*5·54*	13·8	*0·28*	35·0	*0·71*
14	890—420	715	31·2	—	*0·43*	113	*1·58*	288	*4·03*	232	*3·24*	33·8	*4·72*
15	420—830	784	67·0	—	*0·85*	317	*4·04*	599	*7·59*	0	*0*	2·4	*0·03*

* Values in this column represent the Cl^- ion.

As the temperature of activation is increased, oxidation becomes more vigorous and the surface area increases. This is indicated by the magnitude of the iodine adsorption, which increases from 75 to 784 according to the temperature and duration of the activation. Below 810°, the iodine adsorption increases steadily with temperature of activation; above 810° the results are not strictly comparable, as the time of activation was shorter

than at the lower temperatures. In order to obtain a quantitative comparison of the areas of different samples of charcoal, a measurer must be employed, the adsorption of which is not influenced by changes in the chemical nature of the surface. For this purpose we have found iodine consistently satisfactory, and accordingly, we take the iodine adsorption values recorded in the table as proportional to the areas of the charcoals concerned.

The relative magnitudes of adsorption of acids and bases *per unit area of surface* are expressed by the numbers in *italics* in the table, where the measured adsorption per g. of charcoal has been divided by the iodine adsorption (equivs. $\times 10^{-4}$ per g.) of the same sample. The adsorption of acids is at a minimum (with zero or even negative adsorption in the case of hydrochloric acid) at 400°, and rises steadily to a maximum somewhere in the neighbourhood of 850°, after which it decreases somewhat; with bases, the adsorption is maximum at 400° and slowly decreases (to zero in the case of sodium hydroxide) until 850° is reached, after which it increases (adsorption reappears) again to a small extent. That these results are due to the constitution of the oxide surface produced at the temperature employed for activation, and not merely to the presence of tenaciously held impurities which are progressively removed on increasing the temperature, is shown by activations nos. 14 and 15. In the former, a charcoal activated at 890° (11), possessing considerable adsorptive power for acids and practically none for bases, becomes, after reheating in oxygen at 420°, only half as efficient as an acid adsorbent, while its base adsorption has increased to more than 10 times its former value. No. 15, a base-adsorbing 420° charcoal (4), after reactivation at 830°, would not remove any base from solution, and at the same time became much more efficient as an acid adsorbent.

The 350° activation produced a charcoal with greater acid and less base adsorption capacity than those prepared at slightly higher temperatures. This is probably due to the fact that, at this relatively low temperature, the charcoal surface which had been prepared by carbonising in air at about 700° still retained some of the oxide film characteristic of the higher temperature, and was thus not able to manifest to the full the acidic properties of the low-temperature activated surface.

The results of activations at very high temperatures are interesting, as the adsorption of bases increases (or reappears) while that of acids decreases above 850°. Although this is not in agreement with the observations of all previous workers (Miller prepares base-excluding charcoals at 1000°, and Dubinin reports but does not comment on a slight adsorption of sodium hydroxide on samples activated at that temperature), yet it agrees with earlier work in this series in which the p_H of charcoal suspensions in conductivity water fell considerably from a maximum for the 850° activation (J., 1935, 889) at which catalytic properties (J., 1936, 1688) also go through a point of inflexion. We are not yet in a position to discuss the nature of the change undergone by the carbon surface at 850°, but its effect on the properties of charcoal seems to be fundamental.

Experimental.

Pure sugar charcoal was prepared by carbonising AnalaR sucrose in a silica test-tube, followed by grinding and subsequent evacuation of the product at 750° in silica. The charcoal was then ground in an agate mortar, and screened to 100—200 mesh. As the ash content of the product was only 0·02%, it was considered unwise to subject it to any further purification, which would have involved treatment with acid.

The charcoal was activated by heating small samples, contained in silica trays, in a silica tube furnace in the presence of moist oxygen, as previously described (King and Lawson, *Kolloid-Z.*, **1934**, **69**, 27), the treatment occupying 18 hrs. in activations 1—10 and a shorter period (8—15 hrs.) at the higher temperatures. The rate of flow of oxygen, which was reasonably uniform after the first few minutes, was about 5 c.c. per min. After as rapid cooling as possible, the charcoal was well mixed, and samples of approximately 0·5 g. added to a measured volume of the adsorbate solution. After standing for a day, with shaking, the solutions were filtered, first runnings rejected, and a measured proportion determined volumetrically.

Imperial College, London, S.W. 7. [*Received, July 9th*, **1937**.]

308. *A Micro-flotation Method for the Precise Comparison of Liquid Densities and its Application to a Preliminary Investigation of the Distribution of Heavy Water in Certain Salt Hydrates and to Other Matters.*

By J. S. ANDERSON, R. H. PURCELL, T. G. PEARSON, A. KING, F. W. JAMES, H. J. EMELÉUS, and H. V. A. BRISCOE.

The flotation method of comparing liquid densities previously described has been refined by the use of smaller silica floats and concomitant changes in the technique of purifying samples and observing the flotation temperature so that comparisons with an error not exceeding $\pm$ 0·2γ^d are made with 2—5 c.c. of water obtained from an original sample of about 10 c.c. Temperature control of the thermostat has been improved by using a relatively small mercury regulator controlling the heater current by means of a valve-operated relay circuit. A rapid method for density comparisons within $\pm$ 2·0γ^d is also described.

These methods have been applied to additional survey experiments, especially on waters from cancer tissues, in the study of certain salt hydrates, and in examining the interchange between heavy water and certain amines and cobaltammines. Copper sulphate, hydrated with partly heavy water, on dehydration preferentially retains light water, and the experiments indicate that in this salt hydrated partly with heavy and partly with light water considerable interchange occurs in the solid state at temperatures below 100°.

The hydrochlorides of mono-, di-, and tri-methylamine, ethylamine, aniline, and pyridine, dissolved in heavy water, exchange the whole of the hydrogen linked directly to nitrogen within the duration of an experiment, say, 45 minutes. In agreement with Erlenmeyer and Gartner, various cobaltammines are found to exchange their ammine hydrogen completely with heavy water, but a study of hexamminocobaltic chloride has shown that this exchange proceeds at a measurable rate and may require several hours for completion.

A possible explanation is thus afforded for conflicting results recorded by Bankowski.

THE flotation method of comparing densities described in a previous communication (J., 1934, 1207), although satisfactory in precision and trustworthiness,* was laborious and required a sample of at least a litre. We therefore attempted to refine the method so that, without loss of accuracy, a much smaller silica float and a correspondingly smaller sample could be used. The present communication records the technique whereby density comparisons *with an error not exceeding* $\pm$ *0·2*γ^d *have been made with about 2—5 c.c. of water,* using an original sample of about 10 c.c. only.

Though the use of smaller samples facilitates the process of purification very materially, it involves certain special precautions which are described in the experimental part, notably a closer control of the temperature of the thermostat, a correction for the pressure at which the measurement is made (since the micro-floats appear to be practically incompressible), and extreme care to avoid mechanical damage to the float. It is a notable advantage of the micro-method that since the losses during purification are quite negligible, and there is no rejection of head and tail fractions, there is no risk of changing the isotope ratio by fractional distillation. Further, as the later stages of purification are effected in a vacuum, the specimen is secure from atmospheric contamination and is thoroughly outgassed. On the other hand, the demands made upon the purification process are very exacting, because a quantity of impurity insufficient to produce any appreciable change in the density of a macro-sample may possibly change the density of a micro-sample by 10γ^d.

To illustrate both the sensitivity of the method and the care it demands, the following experience may be cited. During a series of measurements the float was accidently shaken in its tube, and thereafter it was found that the flotation temperature of the specimen had

* It is satisfactory to observe that certain doubts expressed on this point (Rakshit, *J. Physical Chem.*, 1935, **39**, 303) have been shown experimentally to be groundless (Dole and Weiner, *Science*, 1935, **81**, 45).

changed by 0·145°. On examining the float under the microscope it was found that a tiny flake of silica had been chipped off the tip. This, of course, involved a restandardisation of the float.

This technique has been applied in the extension of the survey previously reported (J., 1934, 1207), and especially to certain specimens of water having a possible relationship to the incidence of cancer in man and animals. Some of the earlier results thus obtained suggested that the isotopic ratio in the blood might have some diagnostic value, and although this idea is not supported by the later results, the variations observed may well prove ultimately to have some meaning and it seems, therefore, desirable to record them. In certain cases, such as exchange reactions using water containing 0·5—5% D_2O, where sufficiently precise density comparisons are given by determinations of flotation temperature within ± 0·01°, the process of measurement can be greatly simplified and accelerated. In this way the dehydration of certain salt hydrates, especially copper sulphate pentahydrate, has been examined. Though the results recorded in the experimental part can only be regarded as preliminary, they afford clear indications that on dehydrating copper sulphate light water is preferentially retained in the monohydrate (or heavy water preferentially evolved), and that a considerable interchange occurs between the "monohydrate" water and the rest of the water of hydration in the solid state at temperatures no higher than 100°.

The general theoretical considerations here involved have been clearly set out by Ingold and his collaborators (J., 1934, 1593) and need not be recapitulated. They inferred from their experiments that any structure involved in the linking of water of hydration to ions in solution has a loose and evanescent character. The interchange we have now observed in the solid state would appear to indicate that this is also true for the water of hydration of ions in the crystal lattice of copper sulphate, but, on the other hand, the preferential retention of light water on dehydration seems to imply a "chemical" rather than a "physical" linkage of water. Clearly, further experimental investigation of this matter is desirable, and this we hope to undertake in the near future.

The same technique of density comparison has been applied to a study of the interchange between water and certain cobaltammines. Erlenmeyer and Gartner (*Helv. Chim. Acta*, 1934, **17**, 1008) have stated that interchange in such cases is complete, but Bankowski (*Monatsh.*, 1935, **65**, 266; cf. Erlenmeyer and Lobeck, *Helv. Chim. Acta*, 1935, **18**, 1213) has reported that it is only partial. Our experiments reconcile these conflicting statements by showing that, although the interchange does indeed involve all the ammine hydrogen in such salts, yet it proceeds at a relatively slow rate and was presumably not completed in Bankowski's experiments. A kinetic study of this reaction is now being undertaken.

EXPERIMENTAL.

Purification of Specimens.—The method of purification, although similar in principle to that used previously for large samples, differs therefrom in detail and may be regarded as falling into three main stages: (1) Repeated dry oxidation with air over copper oxide at 800°; (2) distillation with and from sodium peroxide and permanganate; (3) simple distillation in a vacuum. For stage (1) the apparatus shown in Fig. 1 is employed; *A* and *B* are two similar vessels of Pyrex glass, carrying side tubes as shown and fitted with standard interchangeable ground joints. By means of the adaptors *C* and *D*, they are connected through the silica tube *E*, packed with oxidised cylinders of copper gauze isolated from the walls by a wrapping of asbestos paper, and heated by a multiple Bunsen burner. The specimen of water is distilled very slowly from *A*, through *E* into *B*, which is cooled to − 80° with solid carbon dioxide and alcohol, and during the whole distillation a slow current of air, dried over calcium chloride, is drawn through the system by means of an aspirator connected to the side limb of *B*. When the whole of the specimen has thus been distilled over, the apparatus is dismantled, the silica furnace *E* is heated with the blow-pipe throughout its length and especially at the inlet end (*A*) to destroy traces of organic deposit, and then the parts are re-assembled with *A* and *B* interchanged so that the distillation may be repeated.

How effective this procedure is may be inferred from the fact that, with blood as the starting material, only three or four distillations were required to produce a perfectly colourless and odourless specimen of water.

Stage (2) is important, for it removes nitric and nitrous acid, sulphuric and sulphurous acid, and carbon dioxide, all or any of which may be formed as oxidation products during stage (1). In the vessel *F* (Fig. 2), having a sealed-in reflux condenser, the specimen is boiled with sodium peroxide (about 0·01 g.) for about 20 mins. and with added potassium permanganate (about 0·01 g.) for a further 10 mins. Larger samples are poured into *F*: smaller samples, with which loss must be avoided, are transferred to *F* by means of the apparatus shown in Fig. 2, *F* in this case replacing *H*, so that the specimen may be distilled into it directly from *B* (Fig. 1) which replaces *G*.

In every case this same apparatus is used both to transfer the sample from *F* and to effect the final distillations and the transference to the flotation tube. The specimen being at *G*, the traps *J* and *K* are cooled with solid carbon dioxide, the apparatus is thoroughly evacuated, and the cock *L* closed. Then *H* is cooled to − 80° while *J* is allowed to warm up, and *G* is warmed to about 30° so that the specimen and any condensate in *J* distil wholly into *H*. Provided the

Fig. 1.

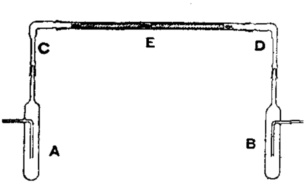
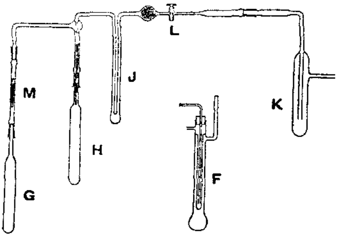


Fig. 2.



specimen has been thoroughly out-gassed, distillation proceeds quite smoothly, but in case any bumping should occur, a trap *M*, packed with glass-wool, is interposed between *G* and *H*. This distillation is then repeated, if necessary, and finally the sample is distilled into the flotation vessel *N* (Fig. 3), which for this purpose is fitted in place of *H*. After the first density determination has been made, the specimen is poured into a clean distilling vessel (*G*) and redistilled into the flotation vessel for a second determination. At the end of a series of determinations the specimen is poured away, and the flotation vessel is pumped dry without washing. To make the apparatus vacuum-tight, the ground joints are lubricated with a very thin film of Apiezon Grease L, which is carefully restricted to the outer part of the joint. Whenever it is observed that the grease has crept, as it must in time, towards the inner parts of the joints, the apparatus is cleaned by digestion with sulphuric–chromic acid mixture, well washed first with tap water and then with good distilled water, and finally steamed out for ½ hour. Immediately after steaming, the joints are capped with tin-foil to keep out dust during cooling, and then the apparatus is set up as before and warmed under vacuum till dry. The joints dry first, and are then greased.

The importance of the trap *J* is evident from the fact that if it be omitted a small head fraction is lost, and specimens containing 0·5% D_2O show after each distillation a rise of flotation temperature (increase of density) of about 0·003°. With specimens much poorer in D_2O, for example the standard tap water, no perceptible change in density results from the rejection of this small head fraction.

The flotation vessel is cleaned only when it becomes contaminated with grease. Then it is pumped dry, washed successively with chloroform, alcohol, and water, soaked overnight in chromic–nitric acid mixture, washed thoroughly with distilled water, and lastly washed with three changes of conductivity water and dried by evacuation. The specimen to be measured is then distilled into the vessel as a final wash and poured back into another vessel for redistillation into the flotation tube for measurement.

The Measurements.—In general, the method of measurement resembles that used with larger floats and need not be described again here. The present floats are about 40 mm. long × 1 mm. diam., and the flotation tube is about 5 mm. internal diameter × 25 cm. long overall, containing a column of water about 7—10 cm. long, representing about 1·5—2 c.c. For small differences of

temperature, the relationship between velocity and Δt for these micro-floats is not materially different from that observed with macro-floats.

In addition to the Calderara thermometers used in the earlier work, two standard Beckmann thermometers were used for the micro-determinations, chiefly because it proved desirable and possible to control the temperature of the bath more precisely. The intervals on the Beckmann thermometers were checked against each other and against the Calderara thermometers: no appreciable difference was observed. Fluctuations of 0·001° in the temperature of the thermostat, which were adequately smoothed out in transmission to a sample of 150 c.c., caused marked variations in the temperature of the micro-specimens of 5—10 c.c. Therefore a more sensitive thermo-regulator was employed, having 16 vertical toluene bulbs, each 20 cm. × 1·2 cm., well distributed throughout the bath. An inner glass vessel of water, 40 cm. × 6 cm., was also used to contain the flotation tube, this inner bath being agitated by a slow stream of air previously raised to the bath temperature. It was found that if the stream of air bubbles exceeded 3—4 per second, an upward drift of temperature occurred, of the order of 0·001° in 10 minutes. Since this drift varied in magnitude with the air stream, it was doubtless due to the conversion of work

FIG. 3.

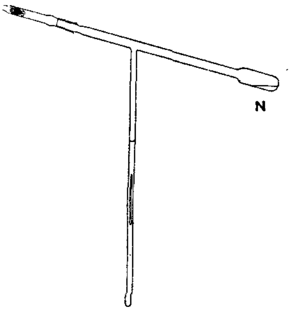
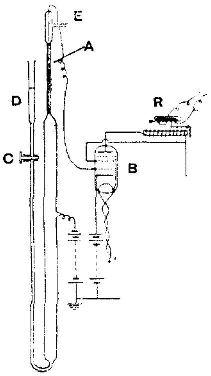


FIG. 4.



into heat. A cooling coil was incorporated in the main thermostat bath, as it was found that this facilitated measurement when the temperature of bath was within 2—3° of its surroundings.

When the heater current was adjusted by the series resistance so that the " on " and " off " periods were about equal, no difficulty was experienced in keeping the temperature of the inner bath constant within ± 0·001° for several hours.

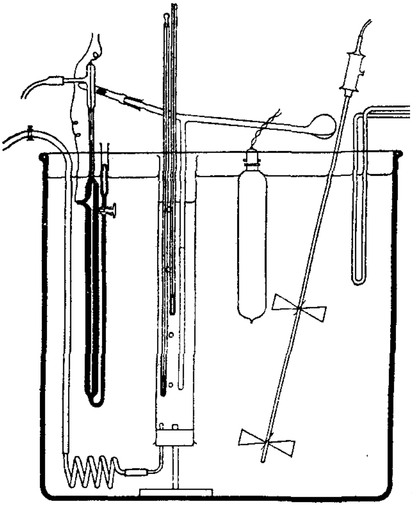
As any vibration of the flotation vessel caused inconsistency in the flotation temperature observed, and produced a movement of the float towards the wall of the tube, the motor and stirrer were carried by a support independent of the bench carrying the thermostat.

Subsequently, it was found advantageous to substitute for the very large toluene–mercury regulator (described above) the much more efficient mercury regulator shown diagrammatically in Fig. 4. This is of Pyrex glass, and the controlling contact is made at *A* between a very fine tungsten wire, sealed through the top, and the column of mercury in a capillary tube about 0·3 mm. in diameter. This contact is inserted in the control grid circuit of an indirectly heated pentode valve *B* of the type commonly employed in the output stage of a broadcast receiver. The potentials applied to the anode, the auxiliary grid, and the cathode are such that when the control grid circuit is closed there is a negligible current in the anode circuit. On opening the control grid circuit by breaking contact at *A*, a current of about 40 milliamps. flows in the anode circuit and serves to actuate a moderately sensitive mercury-switch relay *R* controlling the heater current. At first some irregularity in action was experienced: this was traced to the effect of leakage along the glass surface from mercury to tungsten and was immediately elimin-

ated by covering the mercury with heavy liquid paraffin. Under these conditions the operation of the regulator is highly reliable and so sensitive that with a mercury-filled bulb of only about 60 c.c. capacity the bath temperature could be held constant within the readable limits (± 0·001°) for many hours at a stretch. Indeed, the sensitiveness is such that variations of atmospheric pressure, by varying the size of the regulator bulb, have an appreciable effect on the temperature at which the regulator operates. For this reason the top of the regulator must be closed to maintain the pressure constant. Regulation of the operating temperature is simple, as a coarse adjustment is afforded by the cock *C* in conjunction with the reservoir *D*, while a fine adjustment is secured by expansion or contraction of the bulb itself, by controlling through *E* the air pressure above the mercury.

Evidently, variations in the valve circuit are possible, and several other arrangements of this type have been described (see, *e.g.*, Beaver and Beaver, *J. Ind. Eng. Chem.*, **1923**, **15**, 359; Hutchinson's Testing Apparatus Ltd., *J. Sci. Instr.*, 1934, **11**, 227; Folley and Temple,

FIG. 5.



ibid., 1935, **12**, 392; Temple, *ibid.*, **1936**, **13**, 414). It seems worth while, however, to emphasise the practical value of this device, and to point out the importance for its success of using tungsten contacts sealed through Pyrex, of immersing the contacts in oil, and of controlling the pressure in the regulator.

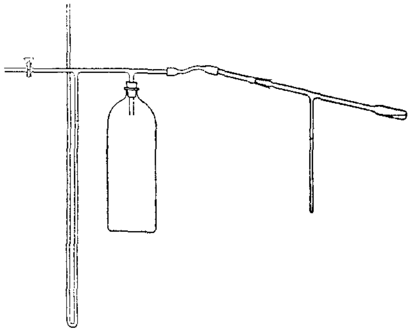
The general arrangement of the thermostat is shown in Fig. 5.

Effect of Pressure Change on the Flotation Temperature.—In the early stages of the present investigation the flotation tube was protected by means of a closed cap, and the flotation temperatures observed were very erratic. A suspicion that these variations were due to pressure changes (which must, of course, accompany temperature changes in a closed tube) was confirmed by direct experiment with the apparatus shown in Fig. 6, whereby any desired pressure difference could be applied to the atmosphere in the flotation tube. The results for floats No. 1 and No. 2 showed that there is a linear relationship between pressure and flotation temperature, a change of 0·001° in the latter resulting from a pressure change of 0·52 cm. Hg for No. 1 and 0·54 cm. Hg for No. 2. It appears therefore that these small floats are practically in-

compressible—a striking difference from the macro-floats, which showed no pressure effect over a range of ± 30 cm. Hg and so, by mere chance, were almost exactly as compressible as water.

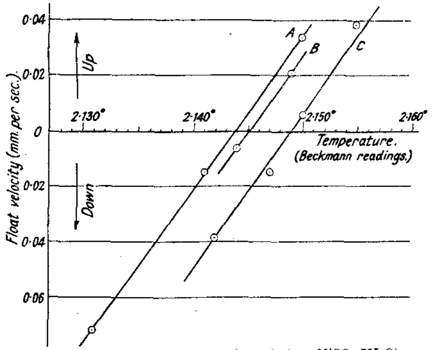
The general consistency of the results and the apparent validity of the correction for pressure differences are illustrated by the data for a single sample of water given in Fig. 7.

FIG. 6.



In some of the later interchange experiments, where fairly heavy water containing 1% or more of D_2O was used, it became convenient to employ a less precise and more speedy method of comparing flotation temperatures. The bath in this case is a 2-litre cylindrical silvered Dewar vessel, with clear strips for observation. It is heated by a steam jet, cooled by circulation of water in a cooling tube, and stirred as required by a stream of air. The temperature of the bath can thus be very quickly adjusted and can be held constant within ± 0·01° for several minutes, a time sufficient for observation of the micro-float when flotation temperatures within ± 0·01° ≡ ± 2·0γ^d are accurate enough for the purpose in hand.

FIG. 7.



Typical flotation curves (sample from $NiSO_4,7H_2O$).
Curve A. Barometer 736 *mm.*
,, *B.* ,, 743 ,,
,, *C.* ,, 740 ,,

Corrected values of flotation temperature (768 *mm.*).
From curve A. 2·138°
,, ,, *B.* 2·140° } *mean* 2·41°.
,, ,, *C.* 2·144°

Results.

The purposes to which this micro-method has been applied are diverse, but may be grouped under two heads: (*a*) an extension of the survey already reported; and (*b*) a preliminary

enquiry into the mode of interchange between heavy water and certain salt hydrates, amines, and ammines.

Additional Survey Experiments.—Since these are in principle quite similar to our earlier survey, they are adequately presented by Table I. We were enabled to examine the specimens of

TABLE I.

Specimen.	T_{H_2O}.	T_S.	$10^3(T_S - T_{H_2O})$.	$\Delta\gamma^{4}$.
Starches.				
Potato starch	*3·623°	3·618° 3·620	+ 4°	+0·8°
Rice starch	3·623	3·607 3·605	+17	+3·4
Wheat starch	3·623	3·616 3·614 3·618	+ 9	+1·8
Alga.				
Spirogyra (by combustion)	3·623	3·623 3·624	0	0
Micas.				
Muscovite (from Tanganyika Territory, E. Africa)	3·623	3·618 3·619	+ 4	+0·8
Muscovite (from Nellore district, Madras, India)	3·623	3·605 3·607	+17	+3·4
Specimens from the Cancer Hospital.				
Normal rat blood, average from 6 rats	3·626 3·626	3·622 3·625 3·623+ 3·623−	+ 3	+0·6
Blood from cancerous rats: average from 6 rats (J.R.S. tumours)	3·624 3·626	3·653 3·650+	−27	−5·4
Water from rat-cancer tissue: average from 6 rats (J.R.S. tumours)	3·640 3·638 3·638 3·643	3·660+ 3·659	−19	−3·8
Normal human blood: man aged 61	3·623	3·623 3·625	0	0
Blood from cancer patient: carcinoma of colon	3·623	3·623 3·623 3·626	0	0
Water from cancer tissue: carcinoma of breast; woman aged 61	3·623	3·620 3·622 3·621 3·618 3·621 3·620	+ 3	+0·6
Normal mouse blood from 25 mice	3·631 3·629 3·629	3·622 3·620+ 3·624−	+ 8	+1·6
Blood of 12 mice with malignant sarcoma	3·630	3·628− 3·628+	+ 2	+0·4
Blood of 12 mice with Crocker sarcoma	3·630	3·622 3·622	+ 8	+1·6
Necrotic tissue, mouse; Crocker sarcoma	3·630	3·630 3·627 3·626	+ 2	+0·4
Breast carcinoma	21·301	21·317 21·318	+17	+3·4
Carcinoma of rectum: blood supplied by Mr. Johnstone	21·301	21·304 21·303	+ 3	+0·6
Carcinoma of breast: primaries. Woman aged 61	21·301	21·302 21·302	+ 2	+0·4
Carcinoma of breast: secondaries. Woman aged 61	21·301	21·306 21·306	+ 5	+1·0
Rat blood; J.R.S. tumour	21·301	21·303+ 21·304	+ 3	+0·6
Cancer tissue: rats; J.R.S. tumours	21·301	21·302 21·301	0	0
Normal mouse blood	21·301	21·310 21·309	+ 8	+1·6
Water from combustion of cholesterol	21·301	21·293 21·295	− 7	−1·4

* All readings of the order of 3° are readings on the arbitrary scale of a Beckmann thermometer.

blood, tissue, etc., dealt with in the lower part of Table I, through the kind collaboration of Professor Kennaway and Dr. Boyland, of the Cancer Hospital, who gave us crude distillates from the various sources. Though no meaning can be attached to the few results here recorded, it seems noteworthy that substantial variations in the isotopic composition of the water are observable in cases of cancer, and may perhaps, by more extended study, later acquire significance.

Investigations by Dole (*J. Amer. Chem. Soc.*, 1935, **57**, 2731; *J. Chem. Physics*, 1936, **4**, 268) and others (*e.g.*, Hall and Jones, *J. Amer. Chem. Soc.*, 1936, **58**, 1915), published since these measurements were made, show that the variation of density found may, where small in magnitude, be due in part to variations in the ratio of the oxygen isotopes: the larger variations, however, must be due to changes in the hydrogen isotopic ratio.

The Dehydration of Copper Sulphate Pentahydrate.—A quantity of crystallised copper sulphate was dehydrated completely by heating to about 300° in a vacuum until no further condensation of water could be observed in a trap cooled to − 80° interposed between the salt and the pump. The anhydrous salt was then recrystallised from heavy water containing about 0·5% D_2O, and the crystals after drainage at the pump and thorough drying between filter-papers, were dehydrated in two stages, so that they first lost 4 mols. of water and later were completely dehydrated. The water evolved at each stage was condensed, and the densities of these two specimens of water were subsequently determined in the micro-flotation apparatus.

Batch I of copper sulphate was first heated in a retort immersed in an oil-bath at 110° until distillation of water ceased. The end-point of this operation was quite sharp and corresponded with the elimination of $4H_2O$. The retort was then connected with an evacuated receiver and heated with a free flame until the remaining molecule of water had distilled over.

Batch II of copper sulphate was dehydrated in a similar fashion, except that the first 4 mols. of water, as well as the remaining molecule, were evaporated off in a vacuum and condensed in a receiver cooled to − 80°. Under these conditions about 95% or more of the fifth molecule can be removed without appreciable decomposition of the salt.

Batch III was dehydrated in the same fashion as Batch I, except that during the first stage the oil-bath was maintained at 120—130°. The results given in Table II were obtained on examining the distillates, the temperature readings being those observed on the arbitrary scale of the Beckmann thermometer, which is, of course, inverted.

TABLE II.

Batch.	Fraction of crystal water.	Flotation temperature. Readings.	Flotation temperature. Mean.	Diff. in flotation temp.
I	1st—4th	2·911°		
		2·914	2·913°	
	5th	3·016		
		3·016	3·016	−0·103°
II	1st—4th	2·452	2·452	
	5th	2·568	2·568	−0·116
III	1st—4th	1·920		
		1·924	1·922	
	5th	1·942		
		1·944	1·943	−0·021

From these data it appears, rather unexpectedly, that in hydrated copper sulphate containing some heavy water the first four molecules eliminated in dehydration are *heavier* than the fifth. All three experiments agree on this point, so there is reason to believe that light water is preferentially held by copper sulphate. A possible alternative view, that heavy water is preferentially eliminated, seems inherently improbable. Nevertheless, the unexplained variations in the data suggest that the phenomenon is complex and, therefore, that no quantitative significance can yet be attached to these results. The difference between the first four molecules and the fifth is greatest in the case where dehydration was effected wholly under vacuum and where, consequently, there was least opportunity for interchange either in the solid or in the vapour phase, and the difference is least in the case where the removal of the first 4 mols. at 120—130° under atmospheric pressure gave conditions which are obviously more favourable for either type of interchange. This also appears to be significant.

In a second experiment anhydrous copper sulphate was first rather less than monohydrated with ½% heavy water and then treated with rather less than 4 mols. of normal water, the water

being introduced slowly as vapour from a cool vessel into the dry solid maintained at about 30° so that no condensation could possibly occur. On dehydrating this salt in the fashion already described, it was again found that the water first evolved was markedly heavy.

In yet another experiment, a quantity of copper sulphate, carefully dehydrated completely in a vacuum, was first partly hydrated with 1% heavy water, slightly less than the quantity required to form the monohydrate being used. This product was then suspended in alcohol, and treated with normal water in quantity almost sufficient to convert the salt into pentahydrate. The salt was then dehydrated first at 100° and later at 300°, the fractions of water being collected separately and with all precautions to avoid their contamination with each other. On examining these the following results were obtained:

Sample.	Flotation temp.	$T_{H_2O} - T_S$.
Standard water	21·10°	—
Stock heavy water	26·74	5·64°
1st—4th H_2O from salt	21·79	0·69
5th H_2O from salt	22·36	1·25

Although a good deal more work is required to elucidate this problem, it seems clear that, as between the first molecule and the remaining molecules of hydrate water, a substantial degree of interchange occurs in the solid state.

Interchange Experiments with Amine Hydrochlorides.—These were carried out by using 1% heavy water and density determinations to ± 0·01°. Quantities of the amine hydrochlorides were weighed out such that each contained the same weight of hydrogen directly attached to nitrogen. Each was then dissolved in 5·00 g. of the same sample of heavy water at a temperature of 40—45°, and after the whole had been kept at about this temperature for 45 minutes, the water was distilled off in a vacuum and purified in the usual manner. The results of the flotation temperature determinations are given in Table III.

TABLE III.

Solute.	Wt. of solute, g.	Wt. of solvent, g.	Flotation temp. of solvent. Initial.	Final.
NH_4Cl	1·00	5·00	26·62°	25·93°
NH_2Me,HCl	1·68	5·00	26·62	25·92
$NHMe_2,HCl$	3·05	5·00	26·62	25·92
NMe_3,HCl	7·14	5·00	26·62	25·85
NH_2Et,HCl	2·03	5·00	26·62	25·92
NH_2Ph,HCl	3·23	5·00	26·62	25·92
C_5H_5N,HCl	8·64	5·00	26·62	25·94
$CO(NH_2)_2$	1·12	5·00	26·62	25·92

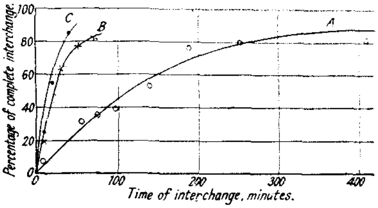
If it be granted that ammonium chloride exchanges four hydrogen atoms with water, it appears that these substituted amines and urea similarly exchange the amino-hydrogen atoms and that of the hydrogen chloride. In the one case, that of trimethylamine hydrochloride, where the result does not accord quite closely with this conclusion, some difficulty was encountered in the process of purification, so that the difference here is probably not significant.

Interchange Experiments with Complex Salts.—Preliminary experiments were made with the following salts dissolved in partly heavy water: (*a*) 1 : 6-Dinitrotetramminocobaltic nitrate, (*b*) carbonatotetramminocobaltic nitrate, (*c*) hexamminocobaltic chloride, (*d*) trisethylenediaminocobaltic chloride. As it was found that in every case interchange occurred, quantitative experiments were begun with (*a*) and (*b*) by making a solution of the salt in partly heavy water, allowing it to stand for about 30 minutes at laboratory temperature and then distilling off the water in a vacuum for subsequent density comparisons. It was soon found that, while considerable interchange occurred, the quantitative results were not reproducible because the interchange, being much slower than was anticipated, was incomplete.

Attempts were then made to follow the progress of the reaction by withdrawing samples at definite times and distilling off the water from these as rapidly as possible in a vacuum. In this way curve *A*, Fig. 8, was obtained, but the method was unsatisfactory, as the samples froze during distillation. Better results (curve *B*) were obtained by putting a relatively large volume of mercury into the sample and shaking continuously during the distillation. An attempt to arrest the reaction by freezing the samples at − 80° and subsequently subliming off the water into a receiver cooled in liquid air failed entirely of its purpose, as, apparently, the exchange proceeds to completion overnight in the solid phase. Finally, a satisfactory method was found

in arresting the exchange by precipitating the complex cobalt salt from the solution as the insoluble mercuric chloride compound. This was carried out by pipetting the sample from the reaction vessel at the desired time and running it immediately on to an excess of finely divided mercuric chloride. The supernatant liquid was then sucked off through a filter and subsequently

FIG. 8.



distilled and purified in the usual way prior to the determination of its flotation temperature. Curve *C* shows that this method gives consistent and apparently trustworthy results. It is thus established that hexamminocobaltic chloride exchanges its hydrogen with water completely but at a measurable rate.

A more extended investigation of the rate of this reaction is being undertaken.

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IMPERIAL COLLEGE, S.W. 7. [*Received, June 8th,* 1937.]

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309. *The Hydration of Acetylenes. Part I. $\Delta^{9:10}$-Undecynoic Acid (Undecolic Acid).*

By (MISS) M. L. SHERRILL and J. C. SMITH.

Although much information is available on the hydration of acetylene to acetaldehyde with sulphuric acid or acetic acid in presence of mercuric salts, the hydration of other acetylenes has not been so carefully studied.

The object of the present research has been to find the proportions of the isomeric keto-acids produced by hydration of $\Delta^{9:10}$-undecynoic acid, $CH_3{\cdot}C{\vdots}C{\cdot}[CH_2]_7{\cdot}CO_2H$. Owing to the greater repulsion of electrons from the polymethylene chain than from the methyl group (general effect), the carbon atom C_{10} will have a negative charge more frequently than will C_9, *i.e.*, $CH_3{\cdot}\bar{C}{\vdots}\overset{+}{C}{\cdot}$, which should lead to a higher proportion of 9-keto-acid in the hydration product. This is found to be true for hydration with sulphuric acid (59% 9-keto-acid and 41% 10-keto acid), but with mercuric acetate in acetic acid the product is 46% of 9-keto- and 54% of 10-keto-acid. Apparently an electromeric rearrangement is induced by the mercuric salt.

ADDITION of hydrogen bromide to $\Delta^{9:10}$-undecenoic acid yielded 50% each of 9- and 10-bromoundecoic acids (Abraham, Mowat, and Smith, this vol., p. 948) so that such different alkyl groups as CH_3 and $[CH_2]_7{\cdot}CO_2H$ did not produce sufficient difference of polarity in the double bond to cause any appreciable orientation of the addition product.

It would be of interest to examine the addition products of hydrogen bromide and the corresponding acetylenic acid ($\Delta^{9:10}$-undecynoic acid) but the difficulties of a quantitative investigation appear serious, and in the meantime a study of the hydration products has been undertaken.

Hydration with sulphuric acid gave 59% of 9-keto- and 41% of 10-keto-undecoic acid, and hydration with mercuric acetate gave 46% of 9-keto- and 54% of 10-keto-acid (compare

Myddleton and Barrett, *J. Amer. Chem. Soc.*, 1927, **49**, 2258). Such a difference between the products of these two methods was unexpected and appeared not to have been observed previously; but the results by each method were very consistent under a variety of conditions, and the difference was not due to loss of one of the isomerides in isolation of the products. As the "general effect" of the alkyl groups should be to make C_{10} more negative than C_9 ($\overleftarrow{CH_3\cdot \underset{-}{C}{:}\underset{+}{C}}\cdot[CH_2]_7\cdot CO_2H$), hydration should produce an excess of 9-keto-acid, and therefore it is the reaction with mercuric acetate in acetic acid which gives the anomalous result. Since the proportion of the isomerides was the same at 40° as at 90°, the effect could not be attributed to temperature, and either the solvent or the mercury salt must be responsible. *An experiment in which a mixture of sulphuric acid (4 mols.) and acetic acid (5 mols.)* was used for hydration gave the same result as sulphuric acid alone, so the acetic acid appeared to exert no influence, and the anomalous result must be attributed to mercuric acetate. It was not possible to test the effect of mercuric salts on the hydration in presence of sulphuric acid because of the sparing solubility of mercuric sulphate in sulphuric acid of sufficient concentration to dissolve the undecynoic acid.

It is possible for an initial complex formed from the undecynoic acid and the mercuric acetate to undergo at least three changes: it may (i) decompose, regenerating the components, (ii) react immediately to form either 9- or 10-keto-acid derivatives depending on the original orientation of the complex, or (iii) undergo a rearrangement and then react to form the keto-acid derivative differing from that indicated by the original orientation. The simplest rearrangement would be that in which the mercuric acetate part of the complex induced the change $CH_3\cdot\overset{-}{C}{:}\overset{+}{C}\cdot$ to $CH_3\cdot\overset{+}{C}{:}\overset{-}{C}\cdot$.

EXPERIMENTAL.

9-Ketoundecoic acid (Abraham, Mowat, and Smith, *loc. cit.*) was crystallised from benzene–light petroleum to constant m. p. 59·0° (thermometer in the liquid) and 57—59·5° (capillary tube). An unstable transparent form melted at 57·2°. 10-Ketoundecoic acid, similarly purified, had m. p.'s 60·2° and 58—60·5° respectively under the same conditions. The unstable form had m. p. 58·45°.

Mixtures of 9- *and* 10-*Ketoundecoic Acids.*—These all crystallised readily, and on the 9-keto-acid branch of the curve the m. p.'s (clearing points) were sharp and unambiguous, only one form of crystal being present. On the 10-keto-acid branch, a bulky mass of crystals melted sharply, leaving a varying amount of fine crystals which in turn cleared sharply. Near the eutectic a third and flocculent type of crystal mass was usually obtained instead of the lowest-melting form. On melting, this left a small residue of the fine, high-melting crystals. Although the

9-Keto-acid, mols. % ..	100	96·8	91·4	85·1	71·9	63·8	58·3	57·0	55·0	53·6	53·1	51·1
M. p. (I)	59·0°	58·05°	56·6°	54·8°	51·1°	48·3°	46·3°	45·7°	45·0°	44·35°	44·2°	43·1°

9-Keto-acid, mols. %	50·0	48·0	46·8	45·3	40·15	30·2	19·8	9·8	0·0
M. p. (I)	43·35°	44·3°	45·25°	46·4°	48·3°	51·8°	54·9°	57·65°	60·2°
,, (II)	—	—	—	45·65°	47·6°	—	—	—	—
,, (III)	42·25°	42·9° (?)	—	—	46·15°	49·7°	53·0°	55·9°	58·45°

conditions governing the formation of each type of crystal were not elucidated, the distinct differences in appearance told immediately which form was being observed, and there was little difficulty in using this branch of the curve for analysis. In consequence of the polymorphism the eutectic m. p. was indefinite but a prolonged halt at 42·4° was observed. For all temperatures below 54° a thermometer was used which involved a slight correction for emergent stem; this correction was not applied, but the same thermometer was used for the m. p.'s of the synthetic mixtures and those of the reaction products.

$\Delta^{9:10}$-*Undecynoic Acid* (Harris and Smith, J., 1935, 1108).—The crude acid (b. p. 132°/0·1 mm., m. p. 56—58°) was crystallised from benzene–light petroleum to constant m. p. 59·9° (thermometer in the liquid), 60—61° (capillary tube).

Hydration of Undecynoic Acid with Sulphuric Acid.—General procedure. Powdered undecynoic acid (5 g.) was gradually added to sulphuric acid (40 c.c., 80—90%) stirred at 5—8°. The resulting solution was kept for ½ hour at 5° and then left for several hours at room temperature;

it gradually darkened. After the mixture had been poured on ice (100—200 g.), extraction with ether gave approximately 5 g. of residue which, distilled at 152—156°/0·1 mm., yielded approx. 4·6 g. of mixed keto-acids. The eutectic m. p. 42·4°, the b. p., and the analysis showed the absence of undecynoic acid [Found in product B (see table): C, 66·0; H, 9·9. Calc.: C, 66·0; H, 10·0%]. Modifications of this procedure are indicated in the table.

Effect of the process of isolation on the yield and composition of the product. The finely ground mixture of keto-acids (3·5 g., m. p. 43·65°, 50·8% of 10-keto-acid) was dissolved in sulphuric acid (30 c.c. of 85% at 8°), and after 6 hours at room temperature the solids were recovered as described above. The distilled product (3·2 g.) had m. p. 44·1°, raised by addition of 10-keto-acid (1%), which corresponded to 51·6% of 10-keto-acid, so the isolation process including distillation had raised the percentage of 10-keto-acid by 0·8%. A mixture of keto-acids (4·00 g.) distilled from the usual apparatus gave 3·82 g. of distillate, a loss of 0·18 g. without change of m. p.

In the table the yields given in parentheses are those obtained after applying the corrections for loss during the isolation process; the figures for the composition of the products have also been corrected.

Hydration with Mercuric Acetate in Acetic Acid.—General procedure. Undecynoic acid (5 g.) in acetic acid (10 c.c.) was added to a clear solution of mercuric acetate (from 14 g. of mercuric oxide) in hot acetic acid (125 c.c.); the mixture was kept for 8 hours at 90°, concentrated in a vacuum to 25 c.c., and the residue heated for 10 minutes at 70° with concentrated hydrochloric acid (30 c.c.) or with 25% sulphuric acid (30 c.c.). The ethereal extract of this mixture was saturated with hydrogen sulphide (to remove mercury compounds), filtered, and evaporated finally in a vacuum. From the residue (approx. 5 g.), distillation gave approx. 4·6 g. of keto-acids, b. p. 151—156°/0·1 mm. The products were faintly yellow, and the eutectic arrests were slightly low, 42·1—42·4°; analysis also indicated a trace of impurity (Found, in product M1: C, 65·6; H, 10·2; *M*, 197. Calc.: C, 66·0; H, 10·0%; *M*, 200). Products M2 and M3 were lighter in colour and had *M*, 199. Any depression of the m. p. would give a lower percentage of 10-keto-acid by the direct reading, and this should be detected by adding sufficient 9-keto-acid to bring the composition on to the other branch of the curve, whereby a low percentage of 9-keto-acid and therefore indirectly a high percentage of 10-keto-acid would be indicated. M1 by direct reading contained 54% of 10-keto-acid; 0·4580 g. of 9-keto-acid added to 1·0158 g. of M1 gave a new mixture of m. p. 46·8°: whence 39·6% of 10-keto-acid in the mixture and 57·5% in M1. M3 by direct reading contained 54% of 10-keto-acid; 0·4757 g. of 9-keto-acid added to 1·5164 g. of M3 had m. p. 46·0°, whence 42% of 10-keto-acid in the mixture and 54% in M3.

Effect of the process of isolation. A solution of mixed keto-acids (3·95 g., 55·4% of 9-keto-acid, m. p. 45·0°) and mercuric acetate (from 10 g. of oxide) in acetic acid (110 c.c.) was kept for 6 hours at 90°. The product, recovered as described above (3·65 g.), had m. p. 44·9° (depressed by addition of 10-keto-acid), indicating 55·0% of 9-keto-acid, so no appreciable change in composition had occurred.

Expt.	Reagent.	Temp.	Time, hrs.	Yield, %.	M. p.'s.	9-Keto-acid, mols. %.
A	H_2SO_4, 85%	5—20°	20	87 (95)	45·8°	58
B	H_2SO_4, 80%	5—20	7	87 (95)	46·1	59
C	H_2SO_4, 80% + $HgSO_4$	,,	18	80 (90)	45·7	58
D	H_2SO_4, 80% + SO_2 + H_2	,,	4	85 (97)	46·35	60
E	H_2SO_4, 85% (19 c.c.) + AcOH (20 c.c.)	35	3	95 (99)	45·4	57
M1	$Hg(OAc)_2$ + AcOH	90	5	—	45·5, 46·3	46
M2	,, ,,	,,	,,	—	45·9, 46·8	45
M3	,, ,,	,,	8	84 (89)	45·5, 46·3	46
M4	,, ,,	40	60	86 (92)	45·3, 46·0	46·5

Admixture of Products of the Two Hydration Processes.—Product M2 (0·7 g.), m. p. 45·9° and 46·8°, was added to product A (0·8 g.), m. p. 45·8°. The new mixture had m. p. 43·1°, indicating that the compositions of the products were on opposite sides of the eutectic.

We are indebted to Mr. E. L. R. Mowat, B.A., for preparation of some of the undecynoic acid.

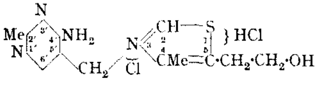
The Dyson Perrins Laboratory, Oxford University. [*Received, July 3rd*, 1937.]

310. *Aneurin. Part VIII. Some Analogues of Aneurin.*

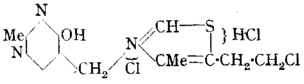
By F. BERGEL and A. R. TODD.

Five analogues of aneurin (vitamin-B_1) are described. Four of these were prepared by methods analogous to that used in the synthesis of aneurin (Part VII, this vol., p. 364), and the fifth by addition of 2 : 4-dichloro-5-chloromethyl-6-methylpyrimidine to 4-methyl-5-β-hydroxyethylthiazole, followed by partial amination of the product. None of these compounds showed measurable vitamin activity. The results suggest that vitamin activity is unlikely in a 3-(pyrimidyl-5'-methyl)thiazolium salt unless it contains (*a*) a 4'-amino-group, (*b*) a 5-hydroxyalkyl group, and (*c*) a free 2-position in the thiazole ring. It is also probable that the nature of the substituents in positions 2' and 6' in the pyrimidine ring influences vitamin activity.

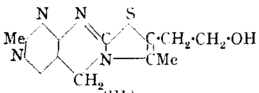
THE question as to how far vitamin activity is associated with details of structure has been investigated in the cases of ascorbic acid (vitamin-*C*) and lactoflavin (vitamin-B_2) by the synthesis of compounds of related constitution. The results obtained in such work indicate clearly that any structural alteration in the vitamin molecule causes a marked diminution in activity, and indeed, often causes its complete disappearance. The structure of aneurin (vitamin-B_1) (I) has been established by complete synthesis (Cline and Williams, *J. Amer. Chem. Soc.*, 1936, **58**, 1504; Todd and Bergel, Part VII, *loc. cit.*; Cline, Williams, and Finkelstein, *J. Amer. Chem. Soc.*, 1937, **59**, 1052), and it is of importance to determine in this case also the structural features essential for vitamin activity. Observations bearing on this point have hitherto been few. The " oxychlorovitamin " (II) of Buchman and Williams (*J. Amer. Chem. Soc.*, 1935, **57**, 1751) has no vitamin activity, which suggests that either, or both, the 4'-amino-group and the hydroxyl in the thiazole side chain are essential.



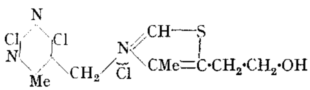
(I.)



(II.)



(III.)



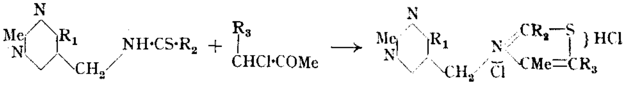
(IV.)

Thiochrome (III) also is inactive (Barger, Bergel, and Todd, Part 1, *Ber.*, 1935, **68**, 2257), but here the presence of the additional ring makes it difficult to draw any valid conclusions. That the methylene bridge between the pyrimidine nucleus and the thiazole nitrogen is necessary, is suggested by the biological inactivity of synthetic 3-pyrimidylthiazolium salts (Todd and Bergel, Part V, J., 1936, 1560). The only other evidence is provided by Bowman (*this vol., p. 494*), *who reported that the substance (IV) was* inactive; in this case also the 4'-amino-group is missing.

In the hope of throwing further light on the problem, we have synthesised several analogues of aneurin having the general formula (VII), by application of the synthetic method described in Part VII (*loc. cit.*). The compounds were tested for vitamin-B_1 activity on rats, Birch and Harris's electrocardiagraphic method (*Biochem. J.*, 1934, **28**, 602) being used, but in no case could measurable activity be detected. The behaviour of each substance in the formaldehyde–azo-test (Kinnersley and Peters, *ibid.*, p. 667) and the thiochrome test (Part I, *loc. cit.*) was noted. The scheme of synthesis and particulars of the individual analogues are indicated on p. 1505.

The synthesis of analogue B (" oxyaneurin ") proved rather difficult. Unsatisfactory results were obtained on condensing 4-hydroxy-5-thioformamidomethyl-2-methylpyrimidine (V; R_1 = OH, R_2 = H) with methyl α-chloro-γ-hydroxypropyl ketone (VI; R_3 =

$CH_2{\cdot}CH_2{\cdot}OH$) or its acetyl derivative. The use of methyl α-bromo-γ-acetoxypropyl ketone and addition of glacial acetic acid to the reaction mixture was more successful.

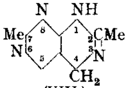


(V.) (VI.) (VII.)

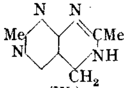
Substance.	R_1.	R_2.	R_3.	Azo-test.	Thiochrome test.
Aneurin	NH_2	H	$CH_2{\cdot}CH_2{\cdot}OH$	+	+
A	NH_2	H	H	—	+
B	OH	H	$CH_2{\cdot}CH_2{\cdot}OH$	+	—
C	OH	H	H	—	—
D	NH_2	Me	$CH_2{\cdot}CH_2{\cdot}OH$	—	—

In the synthesis of analogue D ("*2-methylaneurin*") the necessary *4-amino-5-thioacetamidomethyl-2-methylpyrimidine* (V; $R_1 = NH_2$, $R_2 = Me$) was prepared in good yield from the corresponding 5-aminomethyl compound by allowing it to react in aqueous solution with potassium dithioacetate; this method was more satisfactory than heating the amine with dithioacetic acid. On heating the thioacetamido-compound with methyl α-chloro-γ-acetoxypropyl ketone or the corresponding bromo-ketone at a temperature of *ca.* 130°, the chief product was a crystalline sulphur-free compound considered to be a 2 : 7-*dimethyldihydro*-1 : 3 : 6 : 8-*benztetrazine* of structure (VIII) or (IX). At temperatures below 100° mainly unchanged thioacetamido-compound was isolated. The benztetrazine base was characterised as its *hydrochloride*, *hydrobromide*, and *picrate*; its formation from the thioacetamido-compound is exactly analogous to the production of purines from 4-amino-5-thioformamidopyrimidines by intramolecular loss of hydrogen sulphide (Part V, *loc. cit.*).

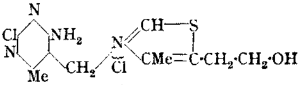
When condensation of the thioacetamido-compound and the bromo-ketone was carried out at 120° in presence of glacial acetic acid, *acetylmethylaneurin* could be isolated in moderately good yield after separation of the above benztetrazine. Decomposition of the *picrate* with hydrochloric acid caused removal of the acetyl group, yielding the *chloride* of *methylaneurin*, whose isolation, like that of its acetyl derivative, was complicated by its great solubility in alcohol. As expected, methylaneurin, which bears a substituent in position 2 of the thiazole nucleus, gave no response in the azo-test or the thiochrome test.



(VIII.)



(IX.)



(X.)

In the course of model experiments preliminary to the synthesis of aneurin (*Nature*, 1936, **138**, 76), we condensed 2 : 4-dichloro-5-chloromethyl-6-methylpyrimidine with 4-methyl-5-β-hydroxyethylthiazole and obtained the salt (IV); this compound has also been prepared by Bowman (*loc. cit.*) by a similar method. The corresponding iodide was prepared in similar fashion from 2 : *4-dichloro-5-iodomethyl-6-methylpyrimidine*. In order to obtain a compound more closely related to the vitamin, (IV) was treated with cold alcoholic ammonia. By analogy with the behaviour of 2 : 4-dihalogenated pyrimidines (cf. Gabriel and Colman, *Ber.*, 1901, **34**, 1254), it was expected that the chlorine atom in position 4′ would be replaced by an amino-group, and that the resulting compound (as chloride) would have structure (X). This view appeared to be confirmed by the fact that oxidation of the product with alkaline potassium ferricyanide gave solutions with a blue fluorescence similar to that of thiochrome; furthermore, a biological test carried out on the crude amination product showed that it possessed some vitamin activity.

We have recently subjected this material to further examination, but have been unable to confirm the earlier observation of biological activity. The substance has certain properties which are not readily explained on the basis of structure (X). It appears to be a

monochloride and yields a monopicrate, which is unexpected in a thiazolium salt of this type. On oxidation with potassium ferricyanide, blue fluorescence develops only in presence of strong alkali, and then rather slowly. Similarly, the response to the azo-test is feeble and much delayed; addition of alkali causes an increase in intensity of colour, but not in rate of its development. We are unable to offer an adequate explanation of these facts, although it might be that the compound exists normally as a derivative of the pseudo-base, formed by migration of the ionic chlorine to the 2-position of the thiazole ring. Attempts to synthesise (X) by the general method used for other aneurin analogues were unsuccessful, as partial amination of 2 : 4-dichloro-5-chloromethyl-6-methylpyrimidine to produce a 5-aminomethyl compound could not be effected.

Although the number of analogues so far prepared is small, it seems probable that any significant alteration in the aneurin molecule will cause almost complete loss of activity. Our results suggest that vitamin activity will be exceedingly feeble, if not entirely absent, in any analogue which does not contain (*a*) an amino-group in position 4′, (*b*) a 5-β-hydroxyethyl group, (*c*) a hydrogen atom in position 2, and (*d*) a methylene group between the pyrimidine nucleus and the thiazole nitrogen. With regard to condition (*b*), it may be that other hydroxyalkyl groups could be substituted for the hydroxyethyl group without loss of activity. The necessity for the presence of a hydroxylated side-chain on the thiazole ring may also be inferred from the results of Lohmann and Schuster (*Naturwiss.*, **1937**, **25**, 26; *Ned. Tijd. Geneesk.*, 1937, 2793), who consider the pyrophosphoric ester of aneurin to be identical with co-carboxylase (cf. Stern and Hofer, *Science*, 1937, **85**, 483; v. Euler and Vestin, *Naturwiss.*, 1937, **25**, 416); phosphorylation of the vitamin can only occur at this point in the molecule—the possibility that it might take place at the 4-amino-group is ruled out by the fact that co-carboxylase gives on oxidation a thiochromine which still contains phosphorus.

As far as chemical tests for aneurin are concerned, it seems as though any thiazolium salt containing a 5-β-hydroxyethyl group and a free 2-position will give a positive azo-test. The thiochrome test will give a positive result with any 3-(pyrimidyl-5′-methyl)thiazolium salt with a free 2-position and a 4′-amino-group, since blue fluorescence is a general property of thiochromines (Part VI; J., 1936, 1601).

EXPERIMENTAL.

3-(4′-Amino-2′-methylpyrimidyl-5′-methyl)-4-methylthiazolium Chloride Hydrochloride (*Analogue* A).—4-Amino-5-thioformamidomethyl-2-methylpyrimidine (0·3 g.) (Part VII, *loc. cit.*) was heated at 115° with chloroacetone (0·2 g.) for about 5 minutes; the mixture liquefied and then became solid again. The cooled product was washed with absolute ether to remove unchanged chloroacetone, and triturated with warm absolute alcohol containing a little hydrogen chloride. The residue was collected and recrystallised from methanol–acetone, forming colourless crystals (0·12 g.), sparingly soluble in absolute alcohol. On heating, the *salt* sintered and blackened at 261—262° but did not liquefy completely below 300° (Found, in material dried at 30°: N, 17·9; S, 10·2; Cl, 22·7. $C_{10}H_{13}N_4ClS,HCl,H_2O$ requires N, 18·0; S, 10·3; Cl, 22·8%). The thiochrome test was positive though weaker than with aneurin, and the azo-test negative. In a biological test 8 mg. showed no aneurin activity.

3-(4′-Hydroxy-2′-methylpyrimidyl-5′-methyl)-4-methyl-5-β-hydroxyethylthiazolium Chloride Hydrochloride (*Analogue* B).—Three methods were tried, in which 4-hydroxy-5-thioformamidomethyl-2-methylpyrimidine (Part VI, *loc. cit.*) was condensed severally with methyl α-chloro-γ-hydroxypropyl ketone (Part III, J., 1936, 1555), methyl α-chloro-γ-acetoxypropyl ketone (*ibid.*), and methyl α-bromo-γ-acetoxypropyl ketone (Research Corporation, E. P. Appln. 1936, No. 7927). Of these, only the third proved satisfactory.

The thioformamido-compound (0·5 g.) and methyl α-bromo-γ-acetoxypropyl ketone (0·6 g.) were heated with glacial acetic acid (2 g.) at 80—100° during 10 minutes. On addition of ether to the resulting solution, an oil was precipitated, which was dissolved in water, and excess of saturated aqueous picric acid added. The oily picrate was washed, decomposed by dissolution in hydrochloric acid (10%), and the picric acid extracted with ether. The aqueous solution was evaporated to dryness in a vacuum, and the residue, which could not be readily recrystallised, was purified by repeated dissolution in absolute alcohol and precipitation with dioxan. In this way a hygroscopic crystalline product was obtained which, on heating, frothed somewhat at

170° and became completely molten at 195—197°. The azo-test was positive, and the thiochrome test negative. In a dosage of 1 mg. the *substance* had no vitamin activity (Found, in material dried at 40° in a high vacuum : C, 42·7; H, 5·1; Cl, 20·3. $C_{12}H_{16}O_2N_3ClS,HCl$ requires C, 42·6; H, 5·0; Cl, 21·0%).

3-(4'-Hydroxy-2'-methylpyrimidyl-5'-methyl)-4'-methylthiazolium Chloride Hydrochloride (*Analogue* C).—When 4-hydroxy-5-thioformamidomethyl-2-methylpyrimidine (0·5 g.) and chloroacetone (0·4 g.) were heated together at 105—115° for 5 minutes, the initially liquid mixture suddenly solidified. After being washed with ether, the product was dissolved in absolute alcohol (30—40 c.c.), and acetone added till a turbidity appeared. On standing, colourless crystals separated, which, when recrystallised from a mixture of methyl and ethyl alcohol (1 : 1) to which a little acetone was added, formed prisms (0·35 g.) which had no definite m. p. but shrank and softened at about 220° [Found, (*a*) in material dried at 30° in a high vacuum : C, 38·3; H, 4·6. $C_{10}H_{12}ON_3ClS,HCl,H_2O$ requires C, 38·2; H, 4·8%; (*b*) in material dried at 40° in a high vacuum : N, 14·2; Cl, 24·8. $C_{10}H_{12}ON_3ClS,HCl$ requires N, 14·3; Cl, 24·2%]. The azo-test and the thiochrome test were both negative, and in a dosage of 8 mg. no vitamin activity could be detected.

4-Amino-5-thioacetamidomethyl-2-methylpyrimidine (V; $R_1 = NH_2$, $R_2 = Me$).—Crude 4-amino-5-aminomethyl-2-methylpyrimidine (0·55 g.) (prepared from its hydrochloride by saturating a cold aqueous solution with potassium hydroxide) was heated under reflux for 4 hours with a solution of dithioacetic acid (0·55 g.) in dioxan (15 c.c.). After addition of excess of light petroleum, the brownish precipitate was collected, triturated with a little water, and recrystallised from hot water, affording colourless, stout needles, m. p. 228—229° (Found : N, 28·5. $C_8H_{12}N_4S$ requires N, 28·6%).

The *compound* is more conveniently obtained by dissolving the diamine hydrochloride in water, neutralising it with potassium carbonate, and adding a solution of potassium dithioacetate; on standing, the thioacetamido-compound separates in practically pure condition. This method avoids the preparation of pure dithoacetic acid : the solution of the crude potassium salt obtained in an intermediate stage of its preparation (Pohl, *Ber.*, 1907, **40**, 1304) may be used directly for thioacetylation purposes.

Condensation of 4-Amino-5-thioacetamidomethyl-2-methylpyrimidine with Methyl α-Bromo-γ-acetoxypropyl Ketone.—When the above thioacetamido-compound (0·5 g.) was heated with methyl α-bromo-γ-acetoxypropyl ketone (0·75 g.) and glacial acetic acid (5 drops) to 120° during 20 minutes, the mixture, initially liquid, set to a semicrystalline mass. The product was thoroughly washed with absolute ether, heated with absolute alcohol (5 c.c.) for a few minutes, and cooled, and the sparingly soluble crystalline material (A) (0·3 g.) collected and washed with absolute alcohol (2·5 c.c.).

2 : 7-Dimethyldihydro-1 : 3 : 6 : 8-benztetrazine (VIII *or* IX).—The solid (A) (above), recrystallised from absolute alcohol, formed colourless needles (0·25 g.), m. p. 283—284°. It contained no sulphur and is evidently the *hydrobromide* of 2 : 7-dimethyldihydro-1 : 3 : 6 : 8-benztetrazine (Found : C, 39·9; H, 4·5; Br, 33·3. $C_8H_{10}N_4,HBr$ requires C, 39·6; H, 4·5; Br, 33·3%). With aqueous picric acid it gave a picrate, forming broad yellow needles, m. p. 198—199°. Decomposition of the picrate in the usual manner with 10% hydrochloric acid furnished the hydrochloride, which crystallised from absolute alcohol containing light petroleum in needles, m. p. 269—270° with partial sublimation. The free *base* crystallised on addition of a slight excess of potassium hydroxide solution (15%) to the hydrobromide dissolved in a little water. Recrystallised from hot water, it formed woolly needles, m. p. 169—170° (picrate, m. p. 198—199°) (Found, in material dried at 30° : C, 59·2; H, 6·4; N, 34·4. $C_8H_{10}N_4$ requires C, 59·2; H, 6·2; N, 34·6%). Aqueous solutions of the base show no fluorescence in ordinary light.

3-(4'-Amino-2'-methylpyrimidyl-5'-methyl)-2 : 4-dimethyl-5-β-hydroxyethylthiazolium Chloride Hydrochloride (*Methylaneurin*).—The alcoholic mother-liquor from the above condensation, after removal of the solid (A), was diluted with light petroleum, and the precipitated brownish oil (0·47 g.) dissolved in a small quantity of absolute alcohol (2·5 c.c.). After 2 days, the solution deposited a crystalline solid (0·15 g.); this was collected, purified by dissolution in alcohol and reprecipitation with light petroleum, and recrystallised from butyl alcohol at — 5°. It formed colourless crystals, m. p. 193—194° (Found, in material dried at 30° : C, 36·5; H, 4·8; Br, 32·2. $C_{15}H_{21}O_2N_4BrS,HBr,H_2O$ requires C, 36·0; H, 4·8; Br, 32·0%), and is evidently the *bromide hydrobromide* of *O-acetyl-2-methylaneurin*. The picrate crystallised from water in yellow needles, m. p. 188—189°, and on decomposition with hydrochloric acid (10%) in the usual manner, it afforded 2-methylaneurin chloride. Recrystallised from absolute alcohol containing light petroleum, this formed broad, colourless needles, m. p. 199° (Found, in material dried at 30° :

C, 43·0; H, 6·0; Cl, 18·5. $C_{12}H_{19}ON_4ClS,HCl,H_2O$ requires C, 42·4; H, 6·0; Cl, 19·2%). The picrate crystallised from water in yellow needles, m. p. 218—219°.

The 2-methylaneurin gave no thiochrome test, and only a slight orange coloration in the azo-test. It had no vitamin activity in a dosage of 100γ; similar inactivity was shown by the acetyl derivative.

Other Condensation Experiments.—(*a*) On heating a mixture of the above thioacetamido-compound (1 g.), methyl α-bromo-γ-acetoxypropyl ketone (1·3 g.), and glacial acetic acid (1·2 g.) at 80° for 5 minutes, a solution was formed which on cooling deposited the *hydrobromide* of the original thioacetamido-compound; it crystallised from alcohol in colourless needles, m. p. 198—200° (Found: C, 34·8; H, 4·6. $C_8H_{12}N_4S,HBr$ requires C, 34·7; H, 4·7%). The picrate had m. p. 165°, not depressed by admixture with the picrate (m. p. 165°) prepared directly from the free thioacetamido-compound.

Decomposition of the above picrates with hydrochloric acid gave the *hydrochloride*, m. p. 197—199° (Found: Cl, 14·1; S, 12·6. $C_8H_{12}N_4S,HCl,H_2O$ requires Cl, 14·2; S, 12·8%). By addition of ether to the acetic acid mother-liquors from the above experiment, 2 : 7-dimethyldihydrobenztetrazine hydrobromide, m. p. 283—284° (picrate, m. p. 198—199°), was obtained.

(*b*) By carrying out the condensation of the thioacetamido-compound with the chloro- or the bromo-ketone at 130°, 2 : 7-dimethyldihydrobenztetrazine was formed almost exclusively.

3-(2′ : 4′-*Dichloro-6′-methylpyrimidyl-5′-methyl*)-4-*methyl*-5-β-*hydroxyethylthiazolium Chloride* (IV).—2 : 4-Dichloro-5-chloromethyl-6-methylpyrimidine (2·8 g.) (Part VI, *loc. cit.*; Bowman, *loc. cit.*) was heated to 105° with 4-methyl-5-β-hydroxyethylthiazole (1·75 g.) (Part III, *loc. cit.*; Buchman, *J. Amer. Chem. Soc.*, 1936, **58**, 1803) during 30 minutes. The melt had then solidified, and, after cooling, it was washed thoroughly with absolute ether and recrystallised from absolute alcohol (30—40 c.c.), forming faintly yellowish platelets (1·15 g.), m. p. 206° (Bowman gives m. p. 203—204°) (Found: C, 40·7; H, 3·8; N, 11·7; S, 8·5. Calc. for $C_{12}H_{14}ON_3Cl_3S$: C, 40·6; H, 4·0; N, 11·8; S, 9·0%). The azo-test was positive, but weaker and more delayed than with aneurin; addition of sodium hydroxide increased the intensity of colour. The thiochrome test was negative. The corresponding picrate had m. p. 142°.

2 : 4-*Dichloro-5-iodomethyl-6-methylpyrimidine*.—To 2 : 4-dichloro-5-chloromethyl-6-methylpyrimidine (3·2 g.), dissolved in the minimum amount of acetone, a *N*-solution of sodium iodide in acetone (20 c.c.) was added. The sodium chloride which was immediately precipitated was filtered off, and the *iodo*-compound precipitated by addition of water. It crystallised from light petroleum (b. p. 60—80°) in large, colourless prisms (3 g.), m. p. 93·5—94·5° (Found: C, 23·9; H, 1·8; N, 9·3. $C_6H_5N_2Cl_2I$ requires C, 23·8; H, 1·7; N, 9·3%).

3-(2′ : 4′-*Dichloro-6′-methylpyrimidyl-5′-methyl*)-4-*methyl*-5-β-*hydroxyethylthiazolium Iodide*.—The above iodo-compound (2·1 g.), when heated at 60—70° with 4-methyl-5-β-hydroxyethylthiazole (1 g.) for 5 minutes, yielded a crystalline *iodide*, which was washed with ether and recrystallised from absolute alcohol, forming glistening leaflets, m. p. 181—182° (Found: C, 32·6; H, 3·1; N, 9·2; S, 6·9. $C_{12}H_{14}ON_3Cl_2IS$ requires C, 32·2; H, 3·1; N, 9·4; S, 7·2%). It was similar in properties to the corresponding chloride (above), and gave the same picrate, m. p. 142°.

Amination of the Salt (*IV*).—The chloride (IV) (0·27 g.) was dissolved in 4*N*-alcoholic ammonia (10 c.c.), and the bright yellow solution was kept for 1 hour at room temperature, then evaporated to dryness. The residue was stirred with absolute alcohol containing hydrogen chloride, whereupon most of it dissolved, leaving ammonium chloride. Addition of 2 vols. of acetone to the solution precipitated a small amount of amorphous material, which was filtered off, and the filtrate precipitated with light petroleum. The rather sticky precipitate was collected and spread on a porous plate, which was left for several hours at room temperature in a closed vessel over methanol–acetone (1 : 1); gummy material was thus removed. The crystalline residue was recrystallised from absolute alcohol containing light petroleum. It formed colourless needles which, on heating, shrank at 135° (probably owing to loss of water) and melted at 200—205°. Analysis indicates that it has the composition of the expected 3-(2′-*chloro*-4′-*amino*-6′-*methylpyrimidyl*-5′-*methyl*)-4-*methyl*-5-β-*hydroxyethylthiazolium chloride* (X) (Found, in material dried at 30°: C, 40·9; H, 5·1; N, 15·5; Cl, 21·1; S, 9·1. $C_{12}H_{16}ON_4Cl_2S,H_2O$ requires C, 40·9; H, 5·1; N, 15·9; Cl, 20·1; S, 9·1%). The compound gave positive results in the thiochrome and the azo-test, but the response was feebler than with aneurin and much delayed. The positive thiochrome test is evidence for the presence of a 4′-amino-group. In biological tests no measurable vitamin activity could be detected in doses of 0·5 and 1 mg. The *picrate* had m. p. 214—215° (Found: Cl, 7·2. $C_{18}H_{18}O_8N_7ClS$ requires Cl, 6·7%).

The corresponding iodide was prepared in similar fashion from the iodide corresponding to

(IV); crystallised from absolute alcohol containing light petroleum, it had m. p. 228° (decomp.), and gave the same picrate, m. p. 214—215°, as was obtained from the chloride; it showed no vitamin activity, and gave the same delayed colour tests as the chloride.

Experiments on the Amination of 2 : 4-*Dichloro-5-chloromethyl-6-methylpyrimidine*.—(i) To a solution of the trichloro-compound (4 g.) in absolute alcohol (5 c.c.) was added 4*N*-alcoholic ammonia (20 c.c.), and the mixture left at room temperature for 3 hours. The crystalline precipitate was collected, washed with water to remove ammonium chloride, and recrystallised from alcohol, affording colourless needles (0·5 g.), m. p. 162—163° after slight sintering at 153°. The compound was practically insoluble in water, and this, together with the analytical values, suggests that it is the secondary base *bis*-(2 : 4-*dichloro-6-methylpyrimidyl-5-methyl*)*amine* (Found : C, 39·5; H, 2·9; N, 18·9; Cl, 38·4. $C_{12}H_{11}N_5Cl_4$ requires C, 39·3; H, 3·0; N, 19·0; Cl, 38·7%).

On addition of water to the ammoniacal alcoholic solution remaining after separation of the above compound, an amorphous ether-soluble base (1·9 g.) was precipitated. The mother-liquors contained nothing which would react with potassium dithioformate. Similar results were obtained when amination was carried out under various conditions with aqueous or alcoholic ammonia, or liquid ammonia.

(ii) Attempts were made to replace the chloromethyl group in the trichloro-compound by an aminomethyl group by addition of hexamine and subsequent hydrolysis of the crystalline product. The oil obtained in this way would not react with potassium dithioformate.

THE LISTER INSTITUTE, LONDON. [*Received, July 23rd*, 1937.]

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311. *The Mobility of Groups containing a Sulphur Atom. Part IV.*

By DAVID T. GIBSON.

The use of thiolsulphonic esters to introduce thioalkyl (or thioaryl) groups into compounds containing a reactive methylene group has been studied polarimetrically to determine the effect of alkalinity, the ester group, the thiolsulphonic group, and the groups activating the methylene group. The effect of the last is the most complicated, involving enolisation, an optimum degree of activation, and pseudo-reversibility of the reaction.

THE reaction discovered by Brooker and Smiles (J., 1926, 1723)

$$\begin{matrix}X\cdot CO\\Y\cdot CO\end{matrix}\!>\!CH_2 + \begin{matrix}S\cdot SO_2R\\ | \\ A\end{matrix} \xrightarrow{\text{alkali.}} \begin{matrix}X\cdot CO\\Y\cdot CO\end{matrix}\!>\!CH\cdot SA + R\cdot SO_2Na$$

and extended to sulphonyl derivatives (Gibson, J., 1931, 2637) has now been explored in detail by taking advantage of the change in rotation of the solution when *d*-camphor-thiolsulphonic esters are used (cf. Gibson and Loudon, this vol., p. 487).

The exchange of sulphonyl groups between sulphinates and thiolsulphonic esters showed that the sulphonyl group is a potential anion; consequently, the remainder of the molecule (SA) must be capable of functioning transiently as a cation, and so the above reaction may be regarded as the combination of this cation with the methylene anion. This view is supported by the observations that the reaction is favoured (1) by increasing alkalinity; (2) by a strongly negative entering group A, which increases the acceptor tendency of the group SA; (3) by use of thiolsulphonic esters which liberate a relatively strong sulphinic acid

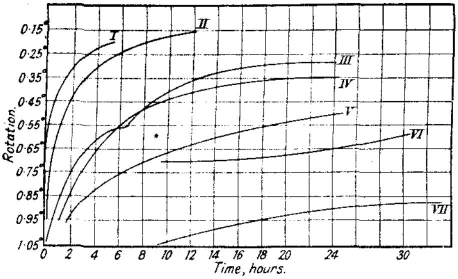
$$(C_6H_3Cl_2\cdot SO_2\cdot S\cdot C_6H_3Cl_2 > C_6H_4Cl\cdot SO_2\cdot S\cdot C_6H_3Cl_2 > C_6H_4Me\cdot SO_2\cdot S\cdot C_6H_3Cl_2).$$

It may be noted that, whereas benzenesulphonyl chloride was found to effect chlorination (J., 1931, 2641), it has now been found that the alkylsulphonyl chlorides may be very advantageously used to introduce an alkylsulphonyl group into reactive methylene compounds.

The effect of the group X, Y, carbonyl, or sulphonyl is more complicated, and evidence has been obtained for the existence of at least three factors, *viz.*, (1) enolisation, (2) pseudo-reversibility, (3) optimum activation, though it is not yet certain to what extent they are connected.

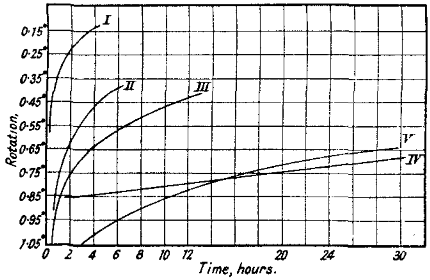
(1) If the compounds examined are arranged according to rate of reaction with methyl *d*-camphorthiolsulphonate, consistent effects of the groups X and Y are only observed when separate comparison is made between (*a*) those which enolise and (*b*) those which, according to Arndt and Martius (*Annalen*, 1932, **499**, 228), do not enolise. It will be seen from Figs. 1 and 2 that the order for (*a*) is approximately $CN > CH_3{\cdot}CO > C_6H_5{\cdot}CO > CO_2C_2H_5 > C_6H_5$, and for (*b*) $CN > C_6H_5{\cdot}CO > CH_3{\cdot}CO > CO_2C_2H_5 > R{\cdot}SO_2 > C_6H_5$.

FIG. 1.



I. *Phenacyl cyanide.*
II. *Ethyl cyanoacetate.*
III. *Acetylacetone.*
IV. *Benzoylacetone.*
V. *Ethyl acetoacetate.*
VI. *Dibenzoylmethane.*
VII. *Ethyl malonate.*

FIG. 2.



I. *Phenylsulphonylacetonitrile.*
II. *Phenylsulphonylacetophenone.*
III. p-*Tolylsulphonylacetone.*
IV. *Ethyl* p-*tolylsulphonylacetate.*
V. *Bisethylsulphonylmethane.*

The position of C_6H_5 in each series is inferred from the behaviour of deoxybenzoin (slight reaction in 2—4 days) and of benzylmethylsulphone (no reaction).

The fact that the rate in the two series is of the same order, however, indicates that extent or ease of enolisation is not a necessary condition of reaction. It is significant, and in agreement with the reaction hypothesis advanced above, that none of the phenolic enol-keto-compounds (phloroglucinol, naphthol, or hydroxyquinoline) which gave positive results (Brooker and Smiles, *loc. cit.*) showed any reaction under the present milder conditions.

(2) Two molecular proportions of methyl camphorthiolsulphonate to each molecule

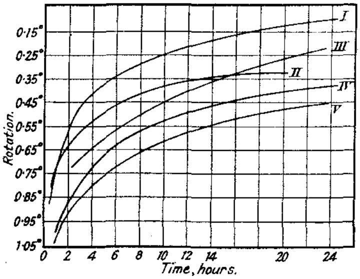
of keto-methylene compound were used to detect, if possible, mono- or di-substitution, for with the former, reaction should come to a standstill at 50%. In fact, with the majority of compounds it ceased at a point in the range 40—70%. Specific tests showed that this appearance of incomplete reaction is not due to side reactions such as (1) oxidation of camphorsulphinic acid to the sulphonic acid, (2) hydrolytic decomposition of the methylene compound $R{\cdot}CO{\cdot}CH_2|CO{\cdot}CH_3$, or (3) exchange of sulphonyl radicals, for this only occurs with alkylthioacetonylsulphones, and then much too slowly to affect the present results; or (4) to a true reversibility of substitution; but probably to a pseudo-reversibility :

$$R{\cdot}SO_2{\cdot}SR + R{\cdot}S{\cdot}CHXY \xrightarrow{H_2O} R{\cdot}SO_2{\cdot}OH + CH_2XY + R{\cdot}S{\cdot}S{\cdot}R$$

(cf. the exchange of alkylthio-groups; J., 1932, 1822).

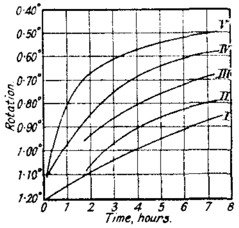
(3) Further, a certain optimum activation of the methylene group is to be expected, for if it is too acidic, the anion $>CH'$ will be a poor donor; whereas if it is too weakly acidic, no hydrogen ion will separate. Confirmation of this was obtained in the observation that, whereas dibenzoylmethane and bisphenylsulphonylmethane both undergo reaction, none was observed with corresponding mono- or tri-derivatives. Failure in case of the latter pair was not due to trisubstituted methanes *per se*, for both ethyl methylmalonate and αα′-bisphenylsulphonylethane react—though slowly. Again, in Figs. 3 and 4 it will be observed that, among the sulphonylacetones and bissulphonyl-

FIG. 3.



I. 4-*Chlorophenylsulphonylacetone.*
II. 2 : 5-*Dichlorophenylsulphonylacetone.*
III. p-*Tolylsulphonylacetone.*
IV. *Methylsulphonylacetone.*
V. 4-*Methoxy*-m-*tolylsulphonylacetone.*

FIG. 4.



I. *Bisethylsulphonylmethane.*
II. *Phenylsulphonylmethylsulphonylmethane.*
III. *Bis*-p-*tolylsulphonylmethane.*
IV. *Bisphenylsulphonylmethane.*
V. *Bis*-4-*chlorophenylsulphonylmethane.*

methanes, increasing acidic strength of the group $R{\cdot}SO_2$ corresponds with increasing reactivity except in the case of the very strongest—2 : 5-dichlorophenylsulphonyl- being definitely less reactive than 4-chlorophenylsulphonyl-acetone (Fig. 3, II). In this connection, too, it is noteworthy that the series (*a*) and (*b*) above do not at all correspond with the " Reihenfolge der acidifizierenden Wirkung " given by Arndt (*loc. cit.*, p. 241).

Certain reactions were examined in connection with hypotheses subsequently discarded : dimethyldihydroresorcinol (reaction just perceptible in 24 hours), *p*-tolylsulphonylacetamide (much slower than ethyl ester), di-*p*-toluoylmethane (slightly but definitely slower than dibenzoylmethane). No reaction was observed with phenylacetonitrile, with ketonic or enolic dibenzoylethane, or with ethyl phenylacetate.

EXPERIMENTAL.

The reaction was investigated by mixing equal volumes of *N*/10-methyl *d*-camphorthiolsulphonate + sodium acetate in alcohol–water (95 : 5) and an *N*/20-solution of the methylene compound in absolute alcohol. Thus the reactants were in the ratio 2 : 1, and the possibility

of disubstitution could be detected. Measurement was made at 20° with mercury green light in 2-dm. tubes. The measurements with 2 : 5-dichlorophenyl esters were made in alcohol–pyridine solution (3 : 1). In the former series, the observed rotation changed from + 1·20° to − 0·20°, in the latter from + 0·60° to − 0·10°.

Methyl *d*-camphorthiolsulphonate is conveniently prepared by adding powdered *d*-camphorsulphonyl chloride gradually to an equal weight of sodium sulphide crystals dissolved in an equal weight of water, and shaking after each addition till the precipitated sulphur has redissolved; the solution is then treated with methyl sulphate (1 mol.), with cooling, and after standing overnight is freed from methyl sulphide and excess of methyl sulphate by brief steam-distillation. The residual oil soon crystallises, and is conveniently purified from ether. The methyl *r*-camphorthiolsulphonate, m. p. 50°, is so much more soluble that even if camphor of inferior optical quality is used, the final product is pure, although the yield naturally suffers.

(1) *The effect of alkali.* Solutions of methyl *d*-camphorthiolsulphonate are (optically) stable to dissolved sodium acetate. Stronger alkali accelerates the Brooker–Smiles reaction, but rapidly decomposes the methyl thiolsulphonate. The use of several mols. of sodium acetate makes no difference.

(2) *The effect of the group* SA. The following are the times (in hours) for reaction at 20° in alcohol–pyridine (3 : 1) with sodium acetate; concentration $N/25$:

	Camphorthiolsulphonate.	
	Methyl.	Dichlorophenyl.
Acetylacetone	6	2
Acetoacetic ester	4	1
Methylsulphonylacetone	6½	4
Ethyl malonate	20 (50% reacted)	20 (full
Bisethylsulphonylmethane	24	7

The times for 50% reaction (in hours) in $N/20$-solution in alcohol–pyridine (1 : 1) with acetylacetone were: SMe, 6; SPh, 2; $S{\cdot}C_6H_3Cl_2$, *ca.* $\frac{1}{6}$ (as soon as observation could be taken).

(3) *The effect of the group* $R{\cdot}SO_2$. A series of esters $R{\cdot}SO_2{\cdot}S{\cdot}C_6H_3Cl_2$ reacted with acetylacetone in presence of lacmoid and sodium acetate. The indicator colour changed to acid in 5 mins. for R = 2 : 5-dichlorophenyl, in 30 mins. for R = 4-chlorophenyl, and in 3—5 hrs. for R = *p*-tolyl or *d*-camphoryl.

The Introduction of Alkylsulphonyl Groups.—An excess of alkylsulphonyl chloride was added to a cold alkaline solution of the reactive methylene compound. After removal of any unchanged material with acetic acid, the required compound separated on acidification with hydrochloric acid. In this manner from $CH_2(SO_2X)(SO_2Y)$, methylsulphonyl chloride gave $CH(SO_2X)(SO_2Y)(SO_2Me)$ in the following cases: X = Ph, Y = *p*-tolyl; X = Ph, Y = Et (J., 1931, 2683); X = *p*-tolyl, Y = Me; X = Ph, Y = Me (J., 1932, 1825). From phenylsulphonylacetophenone, it gave *(phenylsulphonyl)(methylsulphonyl)benzoylmethane*, m. p. 166° (Found: S, 18·2; *M*, 358. $C_{16}H_{14}O_5S_2$ requires S, 18·9%; *M*, 338).

d-Camphorsulphonyl chloride with bisethylsulphonylmethane gave *camphorsulphonylbisethylsulphonylmethane*, m. p. 213° (Found: *M*, 419. $C_{15}H_{26}O_7S_3$ requires *M*, 414). Benzenesulphonyl chloride with methylsulphonylacetone gave diphenyldisulphone; and with bisethylsulphonylmethane, bisethylsulphonyldichloromethane, m. p. 98° (incorrectly reported as the monochloro-derivative, J., 1931, 2642).

Similarly attempts to obtain trisulphonylmethanes with benzenesulphonyl fluoride or β-naphthalenesulphonyl iodide were unsuccessful.

The Incompleteness of Reaction.—(1) The rotation of the solutions changed from positive towards zero, coming to a standstill but never reverting as would have happened if sulphinate had been undergoing oxidation.

(2) Solutions of ethyl acetoacetate and of ethyl toluenesulphonylacetate (selected as giving the flattest curves) were kept for 48 hours with sodium acetate. Thereafter, reaction with methyl camphorthiolsulphonate was exactly the same as with fresh solutions.

(3) A solution of sodium camphorsulphinate with, severally, (i) phenylsulphonyl-α-methylthioacetone, (ii) 4-methoxy-*m*-tolylsulphonyl-α-methylthioacetone, and (iii) methylsulphonylethylsulphonylphenylthiomethane, showed no change.

(4) The exchange of sulphonyl radical takes several days at 60° (Gibson and Loudon, *loc. cit.*).

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UNIVERSITY OF GLASGOW. [*Received, July 17th, 1937.*]

312. *The Unsaturation and Tautomeric Mobility of Heterocyclic Compounds. Part X. The Effect of Ethoxyl Ions on the Methylation of 5-Substituted 1-Anilinobenzthiazoles, and the Ultra-violet Absorption Spectra of 5-Bromo-1-anilinobenzthiazole and of its N-Methyl Derivatives.*

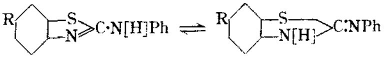
By Robert F. Hunter and M. A. Wali.

On methylation with methyl sulphate alone, 1-anilino-5-methylbenzthiazole, 5-bromo-1-anilinobenzthiazole, and its 5-chloro-analogue all react apparently exclusively in the amino-aromatic form, yielding 1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazoles. The 5-nitro-derivative, however, gives rise to a mixture of isomeric methyl derivatives.

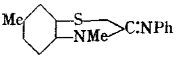
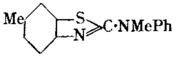
The presence of ethyl-alcoholic sodium ethoxide causes extensive methylation on the non-nuclear nitrogen atom in the 5-methyl-, 5-bromo-, and 5-chloro-bases, and in the case of the 5-nitro-derivative leads to exclusive alkylation at this position.

A comparison of the ultra-violet absorption spectrum of 5-bromo-1-anilinobenzthiazole with that of 5-bromo-1-phenylmethylaminobenzthiazole in ethyl alcohol indicates that the molecule has the amino-aromatic structure. In ethyl-alcoholic sodium ethoxide, there is a lowering of the first maximum, and a pronounced shift towards the region of longer wave-length.

The almost overwhelming tendency for 1-aminobenzthiazoles to react in the amino-aromatic form with methylating agents, giving rise to 1-imino-2-methyl-1 : 2-dihydrobenzthiazoles (Hunter and Styles, J., 1928, 3019; Hunter and Pride, J., 1929, 943) has been attributed (Hunter and Jones, J., 1930, 2190) to the greater stability of this form and to the fact that it permits the formation of the stable sextuple group (Armit and Robinson, J., 1925, 127, 1605; Goss and Ingold, J., 1928, 1268) without calling on the lone pair of electrons of the nuclear nitrogen atom. The presence of the phenyl group of the anilino-substituent in 1-anilinobenzthiazole, however, enables the nitrogen atom to which it is attached to compete with the ring nitrogen atom during methylation, and a similar result has been observed in the cases of the oxazole (Desai, Hunter, and Khalidi, J., 1934, 1186) and selenazole analogues (Chiragh Hasan and Hunter, J., 1935, 1762). It was therefore of interest to examine the 5-substituted 1-anilinobenzthiazoles (I $\rightleftharpoons$ II) analogous to the 1-aminobenzthiazoles studied earlier (Hunter and Jones, *loc. cit.*), in which the 1-anilino-substituent might be expected to decrease the effect of the aromatic conjugation of the heterocyclic ring.

(I.)  (II.)

The methylation of 1-anilino-5-methylbenzthiazole (I $\rightleftharpoons$ II, R = Me), which was first investigated, led to an unexpected result in that the base reacted apparently exclusively in the form (I) with methyl sulphate, giving 1-*phenylimino*-2 : 5-*dimethyl*-1 : 2-*dihydrobenzthiazole* (III), unaccompanied by any detectable quantity of the isomeric 1-*phenylmethylamino*-base (IV), which was rationally synthesised from 1-chloro-5-methylbenzthiazole and methylaniline.

(III.)   (IV.)

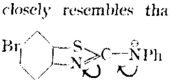
5-*Bromo*- and 5-*chloro*-1-*anilinobenzthiazole* (I $\rightleftharpoons$ II; R = Br and Cl, respectively) behaved similarly, although the halogen substituents are associated with strong polarisation in the sense opposite to that of the methyl group, and gave rise on methylation with methyl sulphate alone to derivatives of type (III), unaccompanied by those of type (IV).

The nitro-group in 5-*nitro*-1-*anilinobenzthiazole* (I $\rightleftharpoons$ II, R = NO_2), however, exhibited the depressing effect on the reactivity of the nuclear nitrogen atom to be anticipated on

account of the high dipole, and the methylation of this base gave rise to a mixture of *5-nitro-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole* and *5-nitro-1-phenylmethylamino-benzthiazole*, in which the former slightly predominated.

Since the absorption spectra of 1-aminobenzthiazoles indicate that the molecules are present in the amino-aromatic form in alcoholic solutions, it was of interest to conduct the methylation of the 5-substituted 1-anilinobenzthiazoles in the presence of ethoxyl ions, whose catalytic influence in three-carbon prototropic changes is well known (Ingold and Shoppee, J., 1929, 447; Kon and Linstead, *ibid.*, p. 1269). It was found that the presence of alcoholic sodium ethoxide *profoundly affects* the course of methylation of 5-bromo-1-anilinobenzthiazole by methyl sulphate. The methyl derivative of type (IV), which could not even be detected in methylation with methyl sulphate alone, now occurred to the extent of about 74% in the methylation product.

The ultra-violet absorption of 5-bromo-1-anilinobenzthiazole in ethyl-alcoholic solution *closely resembles* that of 5-bromo-1-phenylmethylaminobenzthiazole. The absorption curve of 5-bromo-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole, although belonging to the same family, lies to the left and exhibits a lower maximum and higher minimum than either of the former. In ethyl-alcoholic sodium ethoxide, however, 5-bromo-1-anilino-benzthiazole shows a lowering in the first maximum which is probably connected with the production of the ion (V), in which some distribution of anionic charge in the sense of the arrows might be anticipated. The curve also shows a pronounced shift towards the region of longer wave-length, which is probably due to deformation in the Fajans sense.



(V.)

The presence of sodium ethoxide exerted a similar influence on the methylation of 5-chloro-1-anilinobenzthiazole, leading to the production of a mixture containing about 65% of the phenylmethylamino-compound; and it caused 5-nitro-1-anilinobenzthiazole to undergo methylation apparently exclusively on the phenylated nitrogen atom.

The effect of ethoxyl ions was no less striking in the case of 1-anilino-5-methylbenz-thiazole, which, under the conditions described in the experimental section, gave rise to a mixture of (IV) and (III) in which the former predominated to the extent of about 88%.

Experimental.

1-Anilino-5-methylbenzthiazole, prepared by condensation of 1-chloro-5-methylbenzthiazole (m. p. 48°) with aniline, crystallised in needles, m. p. 164° (previously recorded as m. p. 158°).

Methylation of 1-*Anilino-5-methylbenzthiazole.*—(i) A mixture of the anilino-base (2 g.) and methyl sulphate (6 c.c.) was heated on a water-bath under reflux for 3 hours, and the excess of the latter reagent was destroyed with aqueous ammonia (*d* 0·880). An alcoholic solution of the gum thus obtained, on being kept, deposited 1-*phenylimino-2 : 5-dimethyl-1 : 2-dihydrobenzthiazole* (1·5 g.), which on recrystallisation was obtained in needles, m. p. 107—108° (Found: C, 70·8; H, 5·5. $C_{15}H_{14}N_2S$ requires C, 70·8; H, 5·5%); its *picrate* separated from benzene in small yellow crystals, m. p. 180° (Found: S, 6·2. $C_{15}H_{14}N_2S,C_6H_3O_7N_3$ requires S, 6·6%). The alcoholic mother-liquors on concentration deposited unchanged 1-anilino-5-methylbenzthiazole (0·5 g.). A mixture of the above picrate with that of the 1-phenylmethylamino-isomer melted at 166°.

(ii) 1-Anilino-5-methylbenzthiazole (1·5 g.) was dissolved in alcoholic sodium ethoxide (prepared from 0·4 g. of sodium and 14 c.c. of absolute alcohol), and the mixture was heated with methyl sulphate (5 c.c.) and then treated with ammonia as above. On extraction with ether, a gum (1·55 g.) was obtained, which was converted into the picrate (2·75 g.), m. p. 156—168°. On recrystallisation from benzene this gave 0·13 g. of the picrate, m. p. 180—190°. The remainder (m. p. 158—164°) on fractional crystallisation from alcohol gave 0·06 g. of the picrate of unmethyl-ated base, m. p. 228—232°, followed by 0·25 g. of the picrate of 1-phenylimino-2 : 5-dimethyl-1 : 2-dihydrobenzthiazole, m. p. 168—172°. The remainder (2·35 g.) had m. p. 180—190° and was identified as the picrate of 1-phenylmethylamino-5-methylbenzthiazole. The combined yield of this with the first fraction mentioned above, on decomposition with alkali, gave 1-phenyl-methylamino-5-methylbenzthiazole (1·3 g.), m. p. 68—70° after recrystallisation from hexane.

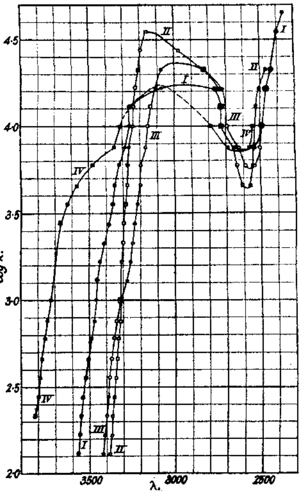
Synthesis of 1-*Phenylmethylamino-5-methylbenzthiazole.*—A mixture of 1-chloro-5-methyl-benzthiazole (2 g.) and methylaniline (1 c.c.) was gently heated until a violent reaction occurred.

The gum obtained on basification with ammonia was dried in a vacuum and recrystallised from cold dilute alcohol, the 1-*phenylmethylamino*-base being obtained in small crystals, m. p. 70—72° (Found: S, 12·3. $C_{15}H_{14}N_2S$ requires S, 12·6%). The *picrate* crystallised in small yellow needles, m. p. 192° (with previous blackening) (Found: S, 6·4. $C_{15}H_{14}N_2S,C_6H_3O_7N_3$ requires S, 6·6%).

5-*Bromo*-1-*anilinobenzthiazole*.—A mixture of 1-chloro-5-bromobenzthiazole (5·7 g.) and aniline (5·7 c.c.) was heated until a vigorous reaction occurred, and the bluish-black product obtained on basification was recrystallised from alcohol (charcoal); the *base* formed small, colourless needles, m. p. 194° (Found: C, 51·3; H, 3·1; S, 10·3. $C_{13}H_9N_2BrS$ requires C, 51·1; H, 3·0; S, 10·4%). The *picrate* crystallised from benzene in short, yellow needles, m. p. 246—247° (Found: S, 6·2. $C_{13}H_9N_2BrS,C_6H_3O_7N_3$ requires S, 6·0%).

Methylation of 5-*Bromo*-1-*anilinobenzthiazole*.—(i) 2 G. of the base were methylated exactly as for the methyl analogue; the gum obtained gradually solidified on keeping, and on recrystallisation from benzene–hexane furnished 5-*bromo*-1-*phenylimino*-2-*methyl*-1 : 2-*dihydrobenzthiazole* (1 g.) in long needles, m. p. 114° (Found: C, 52·8; H, 3·5. $C_{14}H_{11}N_2BrS$ requires C, 52·6; H, 3·4%). The mother-liquors deposited a further quantity of this on keeping, but no evidence of the presence of the isomeric compound was obtained. The *picrate* crystallised from absolute alcohol in silky, yellow needles, m. p. 186—187° (Found: S, 5·8. $C_{14}H_{11}N_2BrS,C_6H_3O_7N_3$ requires S, 5·8%).

(ii) In an experiment similar to the above, the crude methylation product was converted into the picrate, m. p. 178—184°. On fractional crystallisation from benzene, this gave a picrate, m. p. 246—247° (1·1 g.), identified as that of the unmethylated base, and the picrate of 5-bromo-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole, m. p. 182—184° (1·7 g.). The mother-liquors furnished about 0·15 g. of a product, m. p. 150—205°, consisting mainly of the picrate of 5-bromo-1-anilinobenzthiazole contaminated by a certain amount of that of 5-bromo-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole. No evidence was obtained of the presence of the picrate of 5-bromo-1-phenylmethylaminobenzthiazole.



I. 5-*Bromo*-1-*phenylimino*-2-*methyl*-1 : 2-*dihydrobenzthiazole*.
II. 5-*Bromo*-1-*anilinobenzthiazole*.
III. 5-*Bromo*-1-*phenylmethylaminobenzthiazole*.
IV. 5-*Bromo*-1-*anilinobenzthiazole* (*in alcoholic* NaOEt *solution*).

(iii) 5-Bromo-1-anilinobenzthiazole (2 g.) in alcoholic sodium ethoxide (prepared from 0·5 g. of sodium and 15 c.c. of absolute alcohol) was heated with methyl sulphate (6 c.c.), and the mixture treated as before. The gum so obtained was dissolved in alcohol and converted into picrate (3·2 g.), m. p. 172—180°. On fractional crystallisation from benzene, this gave 2·35 g. of 5-bromo-1-phenylmethylaminobenzthiazole picrate, m. p. 196—198°, identified by mixed m. p. determination and regeneration of the base, m. p. 81—82° (1·42 g.), undepressed by admixture with an authentic specimen of 5-bromo-1-phenylmethylaminobenzthiazole. The second fraction (0·65 g., m. p. 184—186°) was identified as 5-bromo-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole picrate by mixed m. p. determination and by regeneration (by treatment with ammonia) of the base, m. p. 110—112° (0·37 g.), undepressed by admixture with the 5-bromo-1-phenylimino-2-methyl base. The third fraction (0·16 g., m. p. 174—180°) could not be purified by recrystallisation, and was therefore decomposed with ammonia, 0·08 g. of impure 5-bromo-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole, m. p. 104—108°, being obtained.

Synthesis of 5-*Bromo*-1-*phenylmethylaminobenzthiazole*.—The gum obtained from 1-chloro-5-bromobenzthiazole (1 g.) and methylaniline (1 c.c.) was kept in a vacuum, triturated with

benzene, and recrystallised from dilute alcohol, the *base* being obtained in small needles, m. p. 82—83° (Found : C, 52·8; H, 3·7. $C_{14}H_{11}N_2BrS$ requires C, 52·6; H, 3·4%). The *picrate* crystallised from absolute alcohol in small yellow needles, m. p. 198° (Found : C, 43·8; H, 2·6; S, 6·0. $C_{14}H_{11}N_2BrS,C_6H_3O_7N_3$ requires C, 43·8; H, 2·6; S, 5·8%).

1 : 5-Dichlorobenzthiazole was prepared by heating diazotised 5-chloro-1-aminobenzthiazole with concentrated hydrochloric acid (Farooq and Hunter, *J. Indian Chem. Soc.*, 1933, **10**, 563), and isolated by distillation in steam. On recrystallisation from alcohol, it was obtained in needles, m. p. 100—101°.

5-Chloro-1-anilinobenzthiazole, obtained from 1 : 5-dichlorobenzthiazole and aniline, separated from alcohol in small needles, m. p. 192° (Found : C, 59·6; H, 3·4. $C_{13}H_9N_2ClS$ requires C, 59·8; H, 3·3%). The *picrate* separated from benzene in small yellow crystals, m. p. 238° (Found : S, 6·3. $C_{13}H_9N_2ClS,C_6H_3O_7N_3$ requires S, 6·5%).

Methylation of 5-Chloro-1-anilinobenzthiazole.—(i) The base (2 g.) was methylated with methyl sulphate (6 c.c.) in the usual way, and the crude product (2·2 g., m. p. 100—112°) treated with benzene. The sparingly soluble residue (0·38 g.) consisted of unchanged material. Fractional crystallisation of the benzene solution furnished *5-chloro-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole* (1·3 g.), which on recrystallisation formed long glistening needles, m. p. 125—126° (Found : C, 61·1; H, 4·0. $C_{14}H_{11}N_2ClS$ requires C, 61·2; H, 4·0%); its *picrate* separated from benzene in small yellow cubes, m. p. 174° (Found : S, 6·1. $C_{14}H_{11}N_2ClS,C_6H_3O_7N_3$ requires S, 6·3%). The base remaining in the benzene mother-liquors was converted into picrate, and the solution was fractionally crystallised, 0·66 g. of crude 5-chloro-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole picrate separating, m. p. 158—162°. A further 0·05 g. of this was obtained on further concentration, but no evidence was obtained of the presence of the picrate of the isomeric phenylmethylamino-derivative.

(ii) 2 G. of 5-chloro-1-anilinobenzthiazole in alcoholic sodium ethoxide were methylated with 6 c.c. of methyl sulphate in the usual way, and the mixture was treated with ammonia. The solid (0·34 g., m. p. 106—120°) which separated from the oil was dissolved in benzene and converted into picrate, affording 0·4 g. of 5-chloro-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole picrate, m. p. 172—174° (regenerated base, m. p. 125—127°). The mother-liquors furnished a further 0·05 g. of this (m. p. 162—168°). The oil which constituted the bulk of the methylation product was converted into picrate (3·2 g., m. p. 160—190°), which was fractionally crystallised from benzene, yielding 2·2 g. of the sparingly soluble picrate of the 5-chloro-1-phenylmethylamino-base, m. p. 196—198° (regenerated base, 1·15 g., m. p. 72—74°). The mother-liquors furnished 0·9 g. of the picrate of the 5-chloro-1-phenylimino-2-methyl base, m. p. 160—164°, from which on recrystallisation and decomposition with alkali, 0·46 g. of this base was obtained. The original aqueous mother-liquors on extraction with ether and treatment of the product with benzene-hexane gave a small amount of unchanged 5-chloro-1-anilino-base (*ca.* 0·02 g.) and 0·15 g. of the base, m. p. 70—74°.

Synthesis of 5-Chloro-1-phenylmethylaminobenzthiazole.—The base obtained from 1 : 5-dichlorobenzthiazole and methylaniline formed a gum which could not be induced to solidify. It was therefore dissolved in benzene and converted into the *picrate*, which crystallised in small yellow needles, m. p. 196—198° (Found : S, 6·0. $C_{14}H_{11}N_2ClS,C_6H_3O_7N_3$ requires S, 6·3%). On decomposition with alkali, this gave the required *base*, which separated from alcohol in small glistening needles, m. p. 76—77° (Found : C, 61·0; H, 4·1. $C_{14}H_{11}N_2ClS$ requires C, 61·2; H, 4·0%).

5-Nitro-1-anilinobenzthiazole separated from benzene in small yellow needles, m. p. 248° (Found : C, 57·6; H, 3·4. $C_{13}H_9O_2N_3S$ requires C, 57·5; H, 3·3%).

Methylation of 5-Nitro-1-anilinobenzthiazole.—(i) The thiazole (2 g.) was methylated as in preceding cases. On crystallisation of the product from ethyl acetate, *5-nitro-1-phenylimino-2-methyl-1 : 2-dihydrobenzthiazole* (1 g.) was obtained, which formed glistening, silky, yellow needles, m. p. 210° (Found : C, 59·1; H, 3·8. $C_{14}H_{11}O_2N_3S$ requires C, 58·9; H, 3·8%), mixed m. p. with 5-nitro-1-anilinobenzthiazole 191°. The mother-liquors on concentration furnished 0·85 g. of crude 5-nitro-1-phenylmethylaminobenzthiazole, m. p. 136—140°, which could not be raised above 143° by recrystallisation. Pure *5-nitro-1-phenylmethylaminobenzthiazole*, prepared for comparison from 1-chloro-5-nitrobenzthiazole and methylaniline, crystallised from acetone in yellow plates, m. p. 152° (Found : C, 59·0; H, 4·05. $C_{14}H_{11}O_2N_3S$ requires C, 58·9; H, 3·8%); its *picrate* formed short yellow needles, m. p. 173° (Found : C, 46·6; H, 2·9; S, 6·2. $C_{14}H_{11}O_2N_3S,C_6H_3O_7N_3$ requires C, 46·7; H, 2·75; S, 6·2%).

(ii) A mixture of the 5-nitro-1-anilino-base (2 g.), alcoholic sodium ethoxide (prepared from 0·5 g. of sodium and 15 c.c. of absolute alcohol), and methyl sulphate (6 c.c.) was heated for 3

hours. On basification and recrystallisation from ethyl acetate, 1·25 g. of 5-nitro-1-phenylmethylaminobenzthiazole (m. p. 138—142°) and 0·27 g. of unchanged 5-nitro-1-anilinobenzthiazole (m. p. 247°) were obtained. The mother-liquors on concentration furnished a further 0·68 g. of the former, m. p. 140—144°, which was identified by mixed m. p. determination with the specimen already described.

Absorption Spectra Measurements.—The measurements were made with a medium Hilger E_2 spectrograph, quartz absorption cells (10 cm. thick) being used.

An $M/1000$-solution of 5-bromo-1-anilinobenzthiazole in absolute alcohol was first examined, and thereafter diluted ten-fold and then 100-fold with the same solvent. A similar procedure was observed with $M/1000$-solutions of 5-bromo-1-phenylmethylaminobenzthiazole and its isomer in alcohol. An $M/1000$-solution of 5-bromo-1-anilinobenzthiazole in $N/100$-ethyl-alcoholic sodium ethoxide was then examined, and the solution subsequently diluted to $M/10,000$ and $M/100,000$.

THE MUSLIM UNIVERSITY, ALIGARH, INDIA. [*Received, July 22nd, 1937.*]

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313. *Derivatives of Hydroxymethoxysuccinic Acids, and Some Related Amides.*

By R. TECWYN WILLIAMS.

Methylation, with methyl sulphate and alkali, of *meso*-tartaric and racemic acid affords *dl*-erythro- and *dl*-threo-α-hydroxy-β-methoxysuccinic acid, respectively. The methyl esters, amides, and methylamides of these acids are described, together with the amides and methylamides of racemic, *meso*-tartaric, and *dl*-dimethoxysuccinic acids.

METHYLATION of *d*-tartaric acid with Haworth's reagents affords *l*-(+)threo-α-hydroxy-β-methoxysuccinic acid (*d*-hydroxymethoxysuccinic acid; Haworth, J., 1915, **107**, 15; Pryde and Williams, J., 1933, 642). Theoretically, six hydroxymethoxysuccinic acids (four active and two racemic) are possible, and these are related in configuration to the tetroses threose and erythrose.

CO_2H	CO_2H	CO_2H	CO_2H
HO·C·H	H·C·OH	H·C·OH	HO·C·H
H·C·OMe	MeO·C·H	H·C·OMe	MeO·C·H
CO_2H	CO_2H	CO_2H	CO_2H
d-Threo-	*l*-Threo-	*d*-Erythro-	*l*-Erythro-

Hydroxymethoxysuccinic acids.

In the present communication, derivatives of dl-*threo*- and dl-*erythro-hydroxymethoxysuccinic acids* are described, these being obtained respectively by methylation of racemic and of *meso*-tartaric acid with methyl sulphate and alkali. The yields of the monomethylated tartaric acids were small, and no evidence of the formation of dimethylated compounds was obtained, although methylation with Purdie's reagents or with diazomethane (Schmidt and Zeiser, *Ber.*, 1934, **67**, 2120) affords dimethylated tartaric acids. The *amides* and *methylamides* of racemic, *meso*-tartaric, and *dl*-dimethoxysuccinic acids have also been prepared.

EXPERIMENTAL.

Methylation of meso-*Tartaric Acid.—Methyl* dl-*erythro-α-hydroxy-β-methoxysuccinate.* 50 G. of *meso*-tartaric acid, obtained by oxidation of maleic acid with sodium chlorate and osmium tetroxide (cf. Hickinbottom, "Reactions of Organic Compounds," p. 12, London, 1936), were neutralised with potassium hydroxide and methylated with 130 c.c. of methyl sulphate and 76 g. of potassium hydroxide (in 100 c.c. of water) during 1 hour, followed by 2 hours' heating on a water-bath. Concentrated sulphuric acid (17 c.c.) was added to the solution, and the whole evaporated to dryness on a water-bath. The dry residue was powdered, and subjected to prolonged ether extraction (Soxhlet). The ether was evaporated, giving 52 g. of an almost colourless stiff syrup, containing a little sulphuric acid. The syrup was dissolved in 115 c.c.

of 1% methyl-alcoholic hydrogen chloride and boiled under reflux for 8 hours. After neutralisation with silver carbonate, filtration, drying over anhydrous magnesium sulphate, and evaporation of the solvent, the residue was extracted repeatedly with boiling benzene. The benzene extract was filtered and set aside to crystallise. Methyl *meso*-tartrate (m. p. 108—110°) which crystallised was separated, and the filtrate evaporated under diminished pressure. The residual pale yellow syrup on distillation in a vacuum gave 7 g. of *methyl* dl-*erythro-hydroxymethoxysuccinate* as a colourless thick liquid, b. p. 107—109° (bath temp.)/ *ca.* 0·5 mm., $n_D^{14°}$ 1·4465, $[\alpha]_D$ 0° (in methyl alcohol) (Found: OMe, 49·6. $C_7H_{12}O_6$ requires OMe, 48·45%).

dl-*Erythro-α-hydroxy-β-methoxysuccindiamide*, obtained by treating the ester with ammonia in methyl alcohol, formed colourless stout needles, m. p. 195—196°, from ether–methyl alcohol (Found: N, 17·0; OMe, 19·3. $C_5H_{10}O_4N_2$ requires N, 17·3; OMe, 19·1%).

Treatment of the ester with a solution of methylamine in methyl alcohol gave the *bismethylamide*, which, after recrystallisation as above, formed tufts of closely-set, deliquescent needles, m. p. 125° (Found, in substance dried in a vacuum at 100°: C, 44·45; H, 7·35; N, 14·7; OMe, 16·5. $C_7H_{14}O_4N_2$ requires C, 44·2; H, 7·4; N, 14·7; OMe, 16·3%). On exposure to air, this compound takes up approximately $2\frac{1}{2}H_2O$, and the m. p. falls progressively during 1—2 hours to 69—70° (Found: C, 36·3; H, 7·9; N, 11·35. $C_7H_{14}O_4N_2,2\frac{1}{2}H_2O$ requires C, 35·8; H, 8·1; N, 11·9%); this *hydrate*, when heated at 100° in a vacuum, becomes anhydrous (Found: loss, 21·5%), then on exposure to air for 3 hours it regains its water (Found: gain, 20·3. $C_7H_{14}O_4N_2,2\frac{1}{2}H_2O$ requires $2\frac{1}{2}H_2O$, 19·1%).

Methylation of Racemic Acid.—*Methyl* dl-*threo-α-hydroxy-β-methoxysuccinate*. Racemic acid (30 g.), methylated with methyl sulphate (60 c.c.) and potassium hydroxide (74 g. in 100 c.c. of water), gave, after separation of methyl racemate (m. p. 85—88°) by means of benzene, 5 g. of the *ester* as a colourless, thick liquid, b. p. 140° (bath temp.) /2 mm., $n_D^{20°}$ 1·4409 (Found: OMe, 47·95%).

dl-*Threo-α-hydroxy-β-methoxysuccindiamide*, prepared in the usual manner, is microcrystalline, m. p. 192—193° (Found: C, 36·9; H, 6·3; N, 16·6; OMe, 19·4%). The *bismethylamide*, crystallised as for its isomer, forms large elongated prisms, m. p. 152—153° (Found: C, 43·8; H, 7·6; N, 14·2; OMe 16·1%).

The following amides were prepared by the action of ammonia in methyl alcohol on the corresponding methyl esters: dl-*Tartramide*, m. p. 226°, rectangular prisms from aqueous methyl alcohol (Found: N, 18·8. $C_4H_8O_4N_2$ requires N, 18·9%); meso-*tartramide*, similarly recrystallised, m. p. 189—190° (Found: N, 18·7%); dl-*dimethoxysuccindiamide*, elongated prisms, darkening at 150° and fusing (decomp.) at 268—272° (Found: OMe, 35·0. $C_6H_{12}O_4N_2$ requires OMe, 35·2%).

Also, the following bismethylamides were prepared by the action of methylamine in methyl alcohol on the methyl esters: dl-*Tartarobismethylamide*, flat wedges, m. p. 204—205°, from methyl alcohol (Found: N, 15·8. $C_6H_{12}O_4N_2$ requires N, 15·9%), meso-*tartarobismethylamide*, minute prisms, m. p. 182—183° (Found: N, 16·0. $C_6H_{12}O_4N_2$ requires N, 15·9%), from ether–methyl alcohol; dl-*dimethoxysuccinobismethylamide*, similarly recrystallised, rods, m. p. 194–195° (Found: OMe, 29·95. $C_8H_{16}O_4N_2$ requires OMe, 30·4%).

The author thanks Dr. W. V. Thorpe for his interest in the work.

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314. *Syntheses in the Octahydropyrrocoline and Octahydropyridocoline Series.*

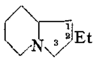
By G. R. CLEMO and T. P. METCALFE.

One of the two unidentified basic compounds obtained by the degradation of strychnine (J., 1936, 1695) has now been shown to be 4-methyl-3-ethylpyridine. 2-Methyloctahydropyridocoline (III) and 1-ethyl- and 2-ethyl-octahydropyrrocoline (I) have been prepared by synthetic methods not previously employed in the preparation of compounds of this type, but no correspondence has been found with the reduced strychnine base. 1-Methyloctahydropyrrocoline, the only hitherto undescribed methyloctahydropyrrocoline having the methyl group in the five-membered ring,

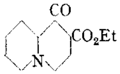
is also described. 2-Keto-octahydropyrrocoline has been synthesised, and from the point of view of the nature of the products of its reduction by the Clemmensen reaction the mechanism of this reaction is discussed.

IN a recent publication on the degradation of strychnine with potassium hydroxide (Clemo, J., 1936, 1695), two unidentified basic compounds, A ($C_8H_{11}N$) and B ($C_{10}H_{11}N$), were described, and the suggestion was made that B was possibly 2-ethylpyrrocoline or methylpyridocoline, a feature of the recent formulæ advanced by Robinson, Leuchs, and others being that the tertiary nitrogen atom of the strychnine molecule is present in either the octahydropyrrocoline or octahydropyridocoline systems, *e.g.*, (I) or (III). The base A has now been proved to be 4-methyl-3-ethylpyridine, by oxidation to pyridine-3 : 4-dicarboxylic acid, and by direct comparison with the synthetic compound made by the method of Rabe and Jantzen (*Ber.*, 1921, **54**, 925), but the base B has not yet been identified. 1-Ethyl- and 2-*ethyl-octahydropyrrocoline* and 2-*methyloctahydropyridocoline* have been prepared, but no correspondence has been found with the reduced base B ($C_{10}H_{19}N$). It is significant, however, that the boiling points of the last base and of 2-methyloctahydropyridocoline are of the same order, and are appreciably higher than those of the other isomeric bases, and since theoretically there are four possible forms of 2-methyloctahydropyridocoline, only two of which have been prepared, the strychnine base may be one of the others.

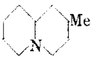
The synthesis of the ethyloctahydropyrrocolines and 2-methyloctahydropyridocoline has required methods not previously employed for the preparation of compounds of this type.



(I.)



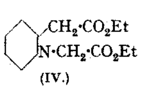
(II.)



(III.)

2-Ethyloctahydropyrrocoline (I) was prepared in very good yield by treating 2-*keto-octahydropyrrocoline* with an excess of ethylmagnesium iodide in ethereal solution, the resulting 2-*hydroxy*-2-*ethyloctahydropyrrocoline* being dehydrated with phosphorus pentachloride, and the *dehydro*-compound catalytically reduced. The isomeric 1-ethyloctahydropyrrocoline was obtained from 1-keto-octahydropyrrocoline (Clemo and Ramage, J., 1932, 2969) in the same way.

When, however, 2-keto-octahydropyridocoline (Clemo, Metcalfe, and Raper, J., 1936, 1429) was treated with methylmagnesium iodide, the yield of 2-hydroxy-2-methyloctahydropyridocoline was extremely small, but 2-methyloctahydropyridocoline (III) was readily prepared by treating the potassio-derivative of ethyl 1-keto-octahydropyridocoline-2-carboxylate (II), for the preparation of which an improved method is given (compare Clemo and Ramage, J., 1931, 437), with methyl iodide. It is noteworthy that the ethyl 1-keto-2-methyloctahydropyridocoline-2-carboxylate so formed was converted under the above conditions, with the loss of the ester group, into 1-*keto*-2-*methyloctahydropyridocoline*. The Clemmensen reduction of this keto-compound gave one form of 2-methyloctahydropyridocoline, and the Wolff reduction gave an isomeric 2-methyloctahydropyridocoline (compare the reduction of 1-keto-octahydropyridocoline to octahydropyridocoline and *nor*lupinane; Clemo, Metcalfe, and Raper, J., 1936, 1429). We were, however, unable to prepare ethyloctahydropyrrocoline by this method, no 1-keto-2-ethyloctahydropyrrocoline being obtained from the reaction of the potassio-derivative of *ethyl* 1-*keto-octahydropyrrocoline*-2-*carboxylate* and ethyl iodide.



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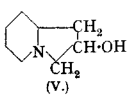

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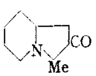

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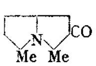

(VII.)

Of the methyloctahydropyrrocolines having the methyl group in the five-membered ring, the 2- and the 3-methyl compound have been previously recorded (Ochiai and Tsuda, *Ber.*, 1934, **67**, 1011; Clemo and co-workers, J., 1935, 1743; 1936, 1429), and the 1-*methyl*

compound has now been prepared by the process used in the preparation of 2-ethyloctahydropyrrocoline. It is rather remarkable that 2-keto-octahydropyridocoline should react differently towards the Grignard reagent from the 1- and the 2-keto-octahydropyrrocoline, and it is significant that models show that, if the first compound exists in the enolic form, a co-ordinate link can be formed without strain between the hydroxylic hydrogen and the nitrogen atom, whilst this is not possible in the other two cases.

2-Keto-octahydropyrrocoline, obtained by the Dieckmann reaction on *ethyl piperidyl-1 : 2-diacetate* (IV), has been reduced by both the Wolff and the Clemmensen reaction to octahydropyrrocoline, the same form of the base being obtained by each method. The Clemmensen reaction is, in this case, of especial interest in that, together with octahydropyrrocoline, *2-hydroxyoctahydropyrrocoline* (V) was also obtained. Two forms of the 2-hydroxy-compound are possible from the reduction of the ketone, and the stereoisomeric form was obtained by reduction of 2-keto-octahydropyrrocoline with sodium amalgam in aqueous-alcoholic solution. Both the alcohols were unchanged after refluxing with amalgamated zinc in concentrated hydrochloric acid solution, and it therefore appears that the mechanism of the Clemmensen reaction does not involve the reduction of the carbonyl group to a secondary alcohol as the intermediate stage, but that direct reduction to the methylene group must occur, the alcohol being produced by a secondary reaction.

In favour of this view, Clemo, Morgan, and Raper (J., 1935, 1743) found that the Clemmensen reduction of 2-keto-3-methyloctahydropyrrocoline (VI) gave only the 2-hydroxy-compound; and the reduction of 4-keto-5 : 5′-dimethyldi(1 : 2)pyrrolidine (VII) (Clemo and Metcalfe, J., 1936, 606) also gave the hydroxy-compound. These two ketones have a methyl group α to the carbonyl, but the position of this methyl group is unlikely to be the cause of the reduction stopping at the hydroxy-stage, since 1-keto-2-methyloctahydropyridocoline, which has a similar structure, is completely reduced.

EXPERIMENTAL.

Ethyl Piperidyl-1 : 2-diacetate.—Ethyl piperidyl-2-acetate (8 g.), ethyl chloroacetate (6·7 g.), and anhydrous potassium carbonate (6 g.) were mixed and heated on the water-bath for 12 hours. Water was added, and the *ethyl* ester extracted with ether and distilled (10·2 g.; b. p. 155°/12 mm., 140°/1 mm.) (Found: C, 60·7; H, 9·1. $C_{13}H_{23}O_4N$ requires C, 60·7; H, 9·0%).

2-Keto-octahydropyrrocoline.—The di-ester (3·4 g.) was added quickly to potassium (1·1 g.), powdered in xylene (8 c.c.) and cooled in ice. The whole was allowed to rise slowly to room temperature, whereupon a vigorous reaction occurred, controlled by cooling in ice, and the reaction mixture solidified. After 2 hours' heating on the water-bath, water (6 c.c.) and concentrated hydrochloric acid (30 c.c.) were added, the solution was heated in the water-bath for 18 hours and evaporated to dryness, and the residue basified with potassium hydroxide solution (50%) and extracted with ether. The ethereal extract, dried over potassium carbonate, gave on distillation the *ketone* as a colourless, mobile liquid (0·75 g.; b. p. 76—77°/11 mm., 61°/1 mm.) (Found: C, 69·2; H, 9·7. $C_9H_{15}ON$ requires C, 69·0; H, 9·4%). It rapidly became brown on keeping. The *picrate* formed bright yellow needles, m. p. 187° (decomp.), from alcohol, in which it is difficultly soluble (Found: C, 46·0; H, 4·7. $C_9H_{15}ON,C_6H_3O_7N_3$ requires C, 45·6; H, 4·4%).

2-Hydroxy-2-ethyloctahydropyrrocoline.—To the Grignard compound prepared from magnesium (2 g.), ethyl iodide (12 g.), and anhydrous ether (15 c.c.), and cooled in ice, 2-keto-octahydropyrrocoline (1·2 g.) in ether (5 c.c.) was added slowly. The two solutions reacted vigorously, and a white solid was formed which dissolved on shaking. After 12 hours at room temperature, wet ether was added to the solution, then water, and finally excess of dilute hydrochloric acid (30%). The slight excess of magnesium was not removed. The aqueous layer was separated, the ether extracted twice with a little dilute hydrochloric acid, the combined aqueous extract evaporated to dryness, and the residue basified and steam distilled, 400 c.c. of the distillate being collected. This was acidified, evaporated to dryness, basified, and extracted with ether. The ethereal extract on fractionation gave the *hydroxy*-compound as a colourless viscous liquid (1·03 g., b. p. 82°/1 mm.) (Found: C, 71·2; H, 11·3. $C_{10}H_{19}ON$ requires C, 71·0; H, 11·2%). In some cases a small amount of unchanged ketone was also obtained. This was removed by conversion of the product into the picrate, the picrate of the ketone being almost insoluble in cold ethyl alcohol, whereas that of the tertiary alcohol is extremely soluble. The *picrolonate* separated from alcohol in greenish-yellow prisms, m. p. 198° (Found: C, 55·4; H, 6·5. $C_{10}H_{19}ON.C_{10}H_8O_5N_4$ requires C, 55·4; H, 6·3%).

2-Ethylhexahydropyrrocoline.—The tertiary alcohol (0·2 g.) was treated with an excess of phosphorus pentachloride, added in small lumps. A vigorous reaction occurred, and was controlled by cooling in ice. The mixture was heated at 100° for 15 minutes, cooled, glacial acetic acid (3 c.c.) added, and the solution refluxed gently for 1 hour. The addition of zinc dust increases the yield, probably by preventing atmospheric oxidation. Hydrochloric acid (1 c.c.) was then added, the solution evaporated to dryness, and the residue basified and steam distilled. A colourless oil passed over in the first few c.c.; solid potassium hydroxide was added to the distillate (15 c.c.), and the oil extracted with ether, dried over potassium carbonate, and distilled. The tertiary alcohol (1·2 g.) gave the *dehydro-base* (0·61 g.; b. p. 50°/1 mm., 73—74°/11 mm.) (Found : N, 9·3. $C_{10}H_{17}N$ requires N, 9·3%). The *picrolonate* separated from alcohol in bright greenish-yellow plates, m. p. 191° (Found: C, 58·0; H, 6·1. $C_{10}H_{17}N,C_{10}H_8O_5N_4$ requires C, 57·8; H, 6·1%). A colourless mobile liquid (0·2 g., b. p. 100°/11 mm.) was also obtained. This contains non-ionic chlorine and is presumably the 2-chloro-2-ethyloctahydropyrrocoline.

The tertiary alcohol (0·1 g.) and finely powdered potassium hydrogen sulphate (0·5 g.) were well mixed and heated in a sealed tube at 130° for 3 hours. The reaction mixture was basified and extracted with ether, and gave the picrolonate, m. p. 191° (0·13 g.), identical with that obtained by dehydration with phosphorus pentachloride.

2-Ethyloctahydropyrrocoline.—The hexahydro-compound (0·25 g.), platinum oxide (0·04 g.), and glacial acetic acid (10 c.c.) were shaken for 12 hours in hydrogen at 100 lb./sq. in. After filtration and addition of hydrochloric acid (2 c.c.), the filtrate was evaporated to dryness, and the residue basified and extracted with ether. The ethereal extract, dried over potassium carbonate, gave the *base* on distillation as a colourless mobile liquid (0·24 g., b. p. 41°/1 mm.) (Found : C, 77·7; H, 12·3. $C_{10}H_{19}N$ requires C, 78·3; H, 12·5%). The *picrate* separated from alcohol in bright yellow needles, m. p. 149° (Found: C, 50·2; H, 6.0. $C_{10}H_{19}N,C_6H_3O_7N_3$ requires C, 50·3; H, 5·8%); and the *picrolonate* in pale yellow needles, m. p. 161° (slight decomp.) (Found : C, 57·4; H, 6·7. $C_{10}H_{19}N,C_{10}H_8O_5N_4$ requires C, 57·6; H, 6·5%); and the methiodide in colourless needles from acetone, m. p. 232° (decomp.).

1-*Hydroxy*-1-*ethylhexahydropyrrocoline.*—To the Grignard compound prepared from magnesium (1·5 g.), ethyl iodide (9·0 g.), and anhydrous ether (12 c.c.) was added 1-keto-octahydropyrrocoline (0·8 g.) in ether (6 c.c.). The white solid which immediately formed, dissolved readily on shaking. The solution was left at room temperature for 24 hours and treated as in the case of the 2-hydroxy-2-ethyloctahydropyrrocoline; the ethereal extract on fractionation gave the tertiary *alcohol* as a colourless, viscous liquid (0·78 g., b. p. 85—87°/1 mm.) (Found: N, 8·1. $C_{10}H_{19}ON$ requires N, 8·3%).

1-*Ethylhexahydropyrrocoline.*—The tertiary alcohol (0·76 g.) was treated with an excess of phosphorus pentachloride as in the case of the 2-ethyl compound (above), the reaction being controlled by cooling in ice. The *hexahydro-base* was obtained as a colourless, mobile liquid (0·4 g., b. p. 74—75°/1 mm.) (Found : N, 9·6. $C_{10}H_{17}N$ requires N, 9·3%). The base was unstable in air, becoming dull yellow within an hour. The *picrolonate* formed light brown aggregates of needles, m. p. 185°, from alcohol (Found : C, 58·2; H, 6·4. $C_{10}H_{17}N,C_{10}H_8O_5N_4$ requires C, 57·8; H, 6·1%).

1-*Ethyloctahydropyrrocoline.*—The hexahydro-compound (0·35 g.) in glacial acetic acid (10 c.c.) was shaken with platinum oxide (0·1 g.) in hydrogen at 100 lb./sq. in. for 6 hours. The filtrate from the platinum was evaporated to dryness, the residue basified, and the octahydro-compound extracted with ether (0·34 g., b. p. 64°/11 mm.). The *picrate* formed bright yellow needles, m. p. 134°, from alcohol (Found: C, 50·0; H, 6·1. $C_{10}H_{19}N,C_6H_3O_7N_3$ requires C, 50·3; H, 5·8%), and the *picrolonate*, dull yellow rosettes of needles, m. p. 176° (Found : C, 57·5; H, 6·7. $C_{10}H_{19}N,C_{10}H_8O_5N_4$ requires C, 57·6; H, 6·5%).

*Ethyl Piperidyl-2-acetate-*1-*β-propionate.*—Ethyl piperidyl-2-acetate (5·1 g.), ethyl β-chloropropionate (5 g.), fused sodium acetate (5 g.), and barium carbonate (3 g.) were mixed, and heated on the water-bath for 7 hours. Water and saturated potassium carbonate solution were added, and the *ethyl* ester extracted with ether and distilled (5·1 g., b. p. 165—169°/11 mm.) (Found : C, 62·2; H, 9·4. $C_{14}H_{25}O_4N$ requires C, 62·0; H, 9·2%).

Ethyl 1-*Keto-octahydropyridocoline-*2-*carboxylate* (*improved method*).—Ethyl 2-carbethoxypiperidyl-1-γ-butyrate (5·1 g.) was added to potassium (1·6 g.) powdered in xylene (10 c.c.), and the mixture cooled in ice. When the vigorous reaction had abated, the mixture was heated on the water-bath for 2 hours and cooled; ether, saturated with water, was added to remove the excess of potassium, and the solution just acidified to Congo-red with dilute hydrochloric acid. The aqueous layer was separated, and the ether extracted twice with a little water. The combined aqueous extract was treated with an excess of solid sodium bicarbonate, and extracted

with ether. The pale yellow ethereal extract, dried over sodium sulphate, gave on distillation the β-keto-ester as a pale yellow liquid (2·85 g., b. p. 131—134°/1 mm. without decomp.).

1-*Keto-2-methyloctahydropyridocoline*.—The β-keto-ester (2·06 g.) in anhydrous ethyl alcohol (1·0 c.c.) was added to a warm alcoholic solution of potassium ethoxide, prepared from potassium (0·36 g.) and ethyl alcohol (1·8 c.c.). After the viscous solution of the potassio-derivative of the keto-ester had stood at room temperature for 15 minutes, methyl iodide (1·2 g.) in ethyl alcohol (1·0 c.c.) was added. The solution became cloudy, and a cream-coloured solid rapidly separated. After 15 minutes the reaction mixture was heated on the water-bath, and the contents of the flask became semi-solid owing to separation of solid. After 30 minutes the mixture was cooled, water (3 c.c.) added, the solution acidified with hydrochloric acid and evaporated to dryness, and the residue basified and extracted with ether. The ethereal extract, dried over potassium carbonate, gave on distillation the *ketone* as a pale yellow, mobile liquid (0·57 g., b. p. 80°/1 mm.) (Found : C, 72·1; H, 10·2; N, 8·7. $C_{10}H_{17}ON$ requires C, 71·8; H, 10·3; N, 8·4%). The *picrate* was difficultly soluble in cold acetone and crystallised in light yellow needles, m. p. 176° (Found : C, 48·9; H, 5·4. $C_{10}H_{17}ON,C_6H_3O_7N_3$ requires C, 48·5; H, 5·1%), and the methiodide formed colourless needles, m. p. 167°, from alcohol–ether.

2-*Methyloctahydropyridocoline*.—The ketone (0·57 g.), amalgamated zinc (5 g.), and concentrated hydrochloric acid (9·5 c.c.) were refluxed for 16 hours after standing at room temperature for 2 hours. The residual zinc amalgam was filtered off, the filtrate evaporated to dryness, and the residue basified and steam-distilled. The colourless oil which passed over in the first few c.c. was extracted with ether. The ethereal extract, dried over potassium carbonate, gave on distillation a colourless mobile liquid (0·34 g., b. p. 56—57°/1 mm.) (Found : C, 78·1; H, 12·2. $C_{10}H_{19}N$ requires C, 78·3; H, 12·5%). The *picrate* crystallised from alcohol in bright yellow plates or needles, m. p. 182° (Found : C, 50·3; H, 5·8. $C_{10}H_{19}N,C_6H_3O_7N_3$ requires C, 50·3; H, 5·8%), and the picrolonate in bright yellow aggregates of needles, m. p. 189°. Attempted fractional crystallisation of the picrate from alcohol or benzene showed it to be homogeneous.

The ketone (0·63 g.) and hydrazine hydrate (0·4 g. of 90%) were gently refluxed for 18 hours. On cooling, the hydrazone separated as a cream-coloured solid. It was taken up in ether, the solution dried over sodium sulphate, and the ether distilled off. The residue (0·55 g.), in ethyl alcohol (3 c.c.), and sodium ethoxide from sodium (0·4 g.) were heated together in a sealed tube at 160° for 14 hours. Water was added, the solution acidified with hydrochloric acid and evaporated to dryness, and the residue basified and extracted with ether. The extract on fractionation gave 2-methyloctahydropyridocoline (0·13 g., b. p. 58°/1 mm.). The *picrate* crystallised from alcohol in bright yellow needles, m. p. 158° (Found: N, 14·9. $C_{10}H_{19}N,C_6H_3O_7N_3$ requires N, 14·7%), and was homogeneous. The picrolonate formed bright yellow plates, m. p. 219°, from alcohol.

1-*Hydroxy*-1-*methyloctahydropyrrocoline*.—To the Grignard compound, prepared from methyl iodide (13·5 g.), magnesium (2·6 g.), and anhydrous ether (4·5 c.c.) and cooled in ice, was added 1-keto-octahydropyrrocoline (1·85 g.) in ether (10 c.c.). A white solid separated but dissolved on shaking, and the solution was left at room temperature for 24 hours; it was then treated as in the case of 2-hydroxy-2-ethyloctahydropyrrocoline and gave the tertiary *alcohol* (1·28 g., b. p. 72—73°/1 mm.) (Found : C, 69·6; H, 11·0; N, 9·2. $C_9H_{17}ON$ requires C, 69·7; H, 11·0; N, 9·0%). A small amount of unchanged ketone was always recovered, and this was easily separated from the tertiary alcohol by conversion into the picrate in cold ethyl-alcoholic solution; the insoluble ketone picrate was filtered off, and the tertiary alcohol recovered from the filtrate. The *picrate* was very soluble in alcohol, and crystallised from alcohol–ether in yellowish-brown prisms, m. p. 142° (Found : C, 46·9; H, 5·4. $C_9H_{17}ON,C_6H_3O_7N_3$ requires C, 46·9; H, 5.2%), and the *picrolonate* in light brown rectangular prisms, m. p. 207°, from alcohol (Found : C, 54·1; H, 5·9. $C_9H_{17}ON,C_{10}H_8O_5N_4$ requires C, 54·4; H, 6·0%).

1-*Methylhexahydropyrrocoline*.—The tertiary alcohol (0·1 g.), cooled in ice, was carefully treated with a slight excess of phosphorus pentachloride, and when the vigorous reaction had ceased, heated in the water-bath for 10 minutes. Glacial acetic acid (4 c.c.) was added, and the solution gently refluxed for 2 hours, and treated as in the case of 2-ethylhexahydropyrrocoline. The *hexahydro-base* (0·05 g., b. p. 70°/11 mm.) was extremely unstable, becoming dull yellow in five minutes, and a tar separated within an hour (Found : C, 77·7; H, 11·4. $C_9H_{15}N$ requires C, 78·8; H, 11·0%). It was also oxidised by an alcoholic solution of picric acid to a deep red solution. The *picrolonate* formed aggregates of light brown prisms, m. p. 183°, from alcohol (Found : C, 57·0; H, 6·0. $C_9H_{15}N,C_{10}H_8O_5N_4$ requires C, 56·85; H, 5·7%).

1-*Methyloctahydropyrrocoline*.—The hexahydro-base (0·25 g.) in glacial acetic acid (15 c.c.) was shaken for 6 hours with platinum oxide (0·1 g.) in hydrogen at 100 lb./sq. in. The filtrate

from the platinum was evaporated to dryness, the residue basified with potassium hydroxide solution (50%), extracted with ether, and distilled, giving the *octahydro-base* as a colourless, mobile liquid (0·23 g., b. p. 62°/11 mm.) (Found: N, 10·2. $C_9H_{17}N$ requires N, 10·1%). The *picrate* formed lemon-yellow prisms, m. p. 191° (decomp.), from alcohol (Found: C, 48·7; H, 5·6. $C_9H_{17}N,C_6H_3O_7N_3$ requires C, 48·9; H, 5·4%), and the *picrolonate* light brown prisms, m. p. 198° (decomp.) (Found: C, 56·5; H, 6·5. $C_9H_{17}N,C_{10}H_8O_5N_4$ requires C, 56·6; H, 6·2%).

Reduction of 2-Keto-octahydropyrrocoline by the Wolff Method.—The ketone (0·87 g.) and hydrazine (0·5 g. of 90%) were gently refluxed for 10 hours, and the hydrazone isolated and treated with sodium ethoxide (from 0·4 g. of sodium) in the usual manner at 160—170° for 18 hours, giving octahydropyrrocoline (0·16 g., b. p. 45°/11 mm.), and a pale yellow, viscous liquid (0·185 g., b. p. 110°/11 mm.), which was not further investigated. The picrate of octahydropyrrocoline crystallised from alcohol in lemon-yellow plates, m. p. 228° (decomp.). Attempted fractional crystallisation of the picrate from alcohol and from benzene showed that it was homogeneous.

Reduction of 2-Keto-octahydropyrrocoline by the Clemmensen Reaction.—The ketone (0·8 g.), amalgamated zinc (10 g.), and concentrated hydrochloric acid (20 c.c.), after standing for 2 hours at room temperature, were gently refluxed for 36 hours. The filtrate from the zinc was evaporated to dryness, and the residue basified and steam distilled. The distillate was acidified and evaporated to dryness, and the residue basified and extracted with ether. The extract gave on distillation octahydropyrrocoline (0·2 g., b. p. 45°/11 mm.). The picrate, crystallised from alcohol, melted at 228°, and was identical with that from the Wolff reduction. A colourless viscous liquid, *2-hydroxyoctahydropyrrocoline* (0·25 g., b. p. 90°/11 mm.) (Found: N, 9·85. $C_8H_{15}ON$ requires N, 9·9%), was also obtained. The *picrate* crystallised from alcohol, in which it is easily soluble, in bright yellow prisms, m. p. 133° (Found: C, 45·7; H, 5·1. $C_8H_{15}ON,C_6H_3O_7N_3$ requires C, 45·4; H, 4·9%); and the *picrolonate* in yellow-ochre aggregates of prisms, m. p. 174° (decomp.) (Found: C, 53·3; H, 6·1. $C_8H_{15}ON,C_{10}H_8O_5N_4$ requires C, 53·3; H, 5·7%).

Under more drastic conditions (addition of zinc chloride) a better yield of the fully reduced base was obtained.

Isomeric 2-Hydroxyoctahydropyrrocoline.—The ketone (0·8 g.), sodium amalgam (30 g. of 4%), absolute alcohol (10 c.c.), and water (2 c.c.) were heated on the water-bath under a reflux condenser for 20 hours, the solution rapidly becoming dark brown. Water (10 c.c.) was added, and the solution decanted from the mercury and steam-distilled. The distillate (80 c.c.) was acidified with hydrochloric acid and evaporated to dryness, and the residue basified and extracted with ether. The extract gave on distillation the secondary *alcohol* as a colourless, viscous liquid (0·16 g., b. p. 95°/14 mm.) (Found: N, 9·8. $C_8H_{15}ON$ requires N, 9·9%). The *picrate*, which was less soluble than that of the 2-hydroxyoctahydropyrrocoline obtained from the Clemmensen reaction, crystallised from alcohol in bright yellow needles, m. p. 175° (Found: N, 14·6. $C_8H_{15}ON,C_6H_3O_7N_3$ requires N, 14·7%).

Ethyl 1-Keto-octahydropyrrocoline-2-carboxylate.—Ethyl 2-carbethoxypiperidyl-1-β-propionate (4·7 g.) was added to potassium (1·6 g.) powdered in xylene (10 c.c.), and the mixture heated on the water-bath for 2 hours. Treated as in the case of the preceding keto-ester, it gave a pale yellow liquid (1·4 g., b. p. 103°/1 mm.) (Found: C, 62·7; H, 8·3. $C_{11}H_{17}O_3N$ requires C, 62·6; H, 8·1%).

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315. bicyclo[1 : 2 : 2]*Aza-1-heptane.*

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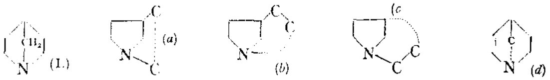
Whereas attempts to prepare derivatives of *bicyclo*[1 : 2 : 2]aza-1-heptane by bridging the 1 : 3-positions of the pyrrolidine ring by each of the three possible routes (see *a*, *b*, *c*, below) have been unsuccessful, we find that the piperidine ring can be easily bridged in the 1 : 4-positions by a single methylene group. An examination of the models, the pyrrolidine ring being assumed to be planar, and the piperidine ring to

react in the " boat " form, shows that ring closure in the first three cases would involve a much greater distortion than in the last case. The synthesis of *bicyclo*[1 : 2 : 2]aza-1-heptane, now described, is simple and gives excellent yields at each stage, and is superior to that recorded by Prelog and Cerkovnikov (*Annalen*, 1936, **525**, 292). Whereas, however, these authors describe the base as a crystalline solid, m. p. 71°, we find it is a colourless, water-like liquid which has not yet shown any sign of crystallising.

For a considerable time we have been working on methods for the synthesis of the bicyclic system (I) and of its derivatives. Many attempts have been made to prepare such compounds by bridging the 1 : 3-positions of the pyrrolidine ring by each of the three possible routes (*a*), (*b*), and (*c*), but all have ended in failure (compare J., 1931, 3185 for similar attempts to bridge the piperidine ring in the *m*-position). The preparation of simple



substituted pyrrolidines of the types (*a*), (*b*), and (*c*) is rendered difficult because of the great stability of the pyrrole nucleus to hydrogenation; for instance, we were unable to hydrogenate ethyl 2-methylpyrrole-3-carboxylate (*Ber.*, 1911, **44**, 493) by platinum and hydrogen in acetic acid solution, or by Rupe's nickel catalyst (*Helv. Chim. Acta*, 1918, **1**, 452) at 140° or 180°.

Ethyl 2 : 2 : 5 : 5-*tetramethylpyrrolidine*-3-*carboxylate*-1-*acetate* has been prepared from ethyl 2 : 2 : 5 : 5-tetramethylpyrrolidine-3-carboxylate (Pauly, *Ber.*, 1903, **36**, 3351) by condensation with ethyl chloroacetate, but it could not be ring-closed by the Dieckmann reaction; neither could a ketone be obtained by distillation of the calcium or thorium salt. Ethyl 2-pyrrolidone-3-oxalate has been prepared from 2-pyrrolidone and ethyl oxalate, but the compound could not be ring-closed (route *b*). Further, ethyl 2-pyrrolidone-1-acetate (Tafel and Wassmuth, *Ber.*, 1907, **40**, 2831) could not be cyclised by the Claisen reaction (route *c*).

Prelog and Cerkovnikov (*Annalen*, 1936, **525**, 292), however, have recently described the preparation of *bicyclo*[1 : 2 : 2]aza-1-heptane from ethyl tetrahydropyrone-4-carboxylate, which was subjected to the Bouveault reaction (33% yield), followed by treatment with hydrobromic acid, giving 1 : 5-dibromo-3-bromomethylpentane (84% yield), and finally with methyl-alcoholic ammonia to give the compound (I) (31% yield). The base was found to melt at 71° and boil at 121°, but it is curious that, although these authors prepared the hydrochloride, picrate, picrolonate, methiodide, aurichloride, and the platinichloride, no m. p.'s are recorded for these derivatives.

Although the systems (*a*), (*b*), and (*c*) could not be cyclised, we have found that the piperidine ring can be easily bridged in the 1 : 4-positions to give system (I). An examination of the models, the pyrrolidine ring being assumed planar, the nitrogen valencies tetrahedral, and the piperidine ring to react in the " boat " form, shows that the ring closure in the first three cases would involve a distortion of about 84° 30′, whereas in the last case the value is only 70° 30′.

The following synthesis of (I) is simple and gives consistently good yields at each stage. 2 : 4-Lutidinic acid, obtained from 2 : 4-lutidine by oxidation, on heating gave pyridine-4-carboxylic acid (Ladenburg, *Annalen*, 1888, **247**, 38), which was reduced with sodium and amyl alcohol and esterified, giving the hitherto unrecorded *ethyl piperidine-4-carboxylate.* Reduction of this ester by the Bouveault reaction gave 4-*piperidylcarbinol* (in 64% yield), which was treated with phosphorus pentabromide, and the resulting 4-piperidylmethyl bromide, when warmed in dilute alkaline solution, readily gave the bicyclic base (I) (in 60% yield calculated from the carbinol). The base was separated from a small amount of the unchanged carbinol by conversion into the picrate. The recovered base, after distillation over sodium in a vacuum, was, however, a colourless, water-like liquid which has not yet shown any sign of crystallising. The facts that it is unchanged by treatment with

p-toluenesulphonyl chloride in alkaline solution, is stable to cold acidified permanganate solution, is unchanged by treatment with hydrogen and platinum in acetic acid, and readily gives a crystalline methiodide exclude the possibility of its being 4-methylene-piperidine. We have repeated Prelog and Cerkovnikov's synthesis, and the picrate, picrolonate, and methiodide made from the liquid base thus obtained correspond in every way with the same derivatives made from our base. Prelog and Cerkovnikov record their hydrochloride as liquefying on exposure to moist air, but we find it to be stable and non-hygroscopic.

EXPERIMENTAL.

Ethyl 2 : 2 : 5 : 5-*Tetramethylpyrrolidine*-3-*carboxylate*-1-*acetate*.—Ethyl 2 : 2 : 5 : 5-tetramethylpyrrolidine-3-carboxylate (9 g.), ethyl chloroacetate (11 g.), and anhydrous potassium carbonate (15 g.) were well mixed and heated for 18 hours at 115°. Water (20 c.c.) was added, and the oil extracted with ether and fractionated, giving the *ester* as a colourless mobile liquid (7·2 g., b. p. 169°/16 mm.) (Found : C, 63·2; H, 9·5. $C_{15}H_{27}O_4N$ requires C, 63·2; H, 9·5%), together with unchanged mono-ester (3·2 g.).

3-*Carboxy*-2 : 2 : 5 : 5-*tetramethylpyrrolidine*-1-*acetic Acid*.—The above diethyl ester (4·8 g.), water (45 c.c.), and concentrated hydrochloric acid (32 c.c.) were refluxed gently for 12 hours. The solution was evaporated to dryness, the residue taken up in hot water and treated with copper carbonate (12 g.), and the filtrate evaporated to 4 c.c., whereupon the deep blue copper salt crystallised (3·6 g.). It was taken up in a little cold water, filtered from a small residue of cuprous chloride, diluted to 100 c.c., warmed, and decomposed with hydrogen sulphide, and the filtrate from the copper sulphide evaporated to dryness. The above *acid* crystallised from hot water in colourless prisms, m. p. 261° (Found : C, 55·65; H, 8·4. $C_{11}H_{19}O_4N,\frac{1}{2}H_2O$ requires C, 55·5; H, 8·4%).

Ethyl 2-*Pyrrolidone*-3-*oxalate*.—A mixture of ethyl oxalate (2 g.) and alcohol-free sodium ethoxide (from sodium, 0·6 g.) in benzene (10 c.c.) was treated with 2-pyrrolidone (1 g.). The pale yellow solution was heated on the water-bath for 10 hours, acidified with dilute acetic acid, and extracted with ether. The pyrrolidone *ester* separated from the concentrated ethereal extract in colourless needles, m. p. 132° (Found : C, 52·6; H, 6·6. $C_8H_{11}O_4N$ requires C, 52·9; H, 6·9%); it was soluble in hot water, the solution being neutral to litmus, and giving a deep red coloration with ferric chloride solution.

Pyridine-4-*carboxylic Acid*.—2 : 4-Lutidine (10 g.) was heated on the water-bath with a solution of potassium permanganate (30 g.) in water (1 l.) till the colour disappeared (8 hours); a further equal amount of potassium permanganate in water (500 c.c.) was added, and the heating continued till the liquid was again decolorised (16 hours). The filtrate from the manganese dioxide was evaporated to 1 litre, acidified to litmus with dilute sulphuric acid, and evaporated to 50 c.c. An equal volume of alcohol was added, the filtrate from the potassium sulphate diluted with water (500 c.c.) and warmed, and 2 : 4-lutidinic acid precipitated as the silver salt by addition of dilute silver nitrate solution. The precipitate, well washed with warm water, was suspended in hot water (250 c.c.) and decomposed with hydrogen sulphide. The 2 : 4-lutidinic acid separated from the filtrate on cooling, and the anhydrous acid (8·0 g.) was obtained by heating at 100° for 2 hours. When heated above its m. p. under diminished pressure (250 mm.), this acid (8·7 g.) evolved carbon dioxide, and the pyridine-4-carboxylic acid (6·4 g.) readily sublimed.

Ethyl Piperidine-4-*carboxylate*.—The mono-acid (5·0 g.) was dissolved in boiling amyl alcohol (300 c.c.) and treated during one hour with sodium (22 g.). The clear solution was cooled somewhat, poured into water (1 l.), and the amyl alcohol distilled off in steam. The residual solution was acidified with hydrochloric acid and evaporated to dryness, the completely dry residue extracted five times with boiling ethyl alcohol (300 c.c. of 95%), and the extract evaporated to dryness. Alcohol (30 c.c.), saturated at 0° with hydrogen chloride, was added to the residue, and, after standing at room temperature for 12 hours, the solution was refluxed gently for 5 hours and evaporated to dryness; the residue was basified with saturated potassium carbonate solution and extracted with ether. The extract, dried over sodium sulphate, gave on fractionation *ethyl piperidine-4-carboxylate* as a colourless mobile liquid (4·4 g., b. p. 74°/1 mm.) (Found : C, 61·1; H, 9·7. $C_8H_{15}O_2N$ requires C, 61·15; H, 9·6%). The *picrate* formed bright yellow needles, m. p. 172°, from alcohol (Found : C, 44·3; H, 4·9. $C_8H_{15}O_2N,C_6H_3O_7N_3$ requires C, 44·5; H, 4·7%). A fraction (b. p. 80°/13 mm.) was also obtained but was not identified. It crystallised from light petroleum (b. p. 40—60°) in rosettes of colourless, deliquescent needles, m. p. 97° (Found : C, 60·7; H, 12·1%).

4-Piperidylcarbinol.—A solution of the above ester (3·3 g.) in anhydrous ethyl alcohol (35 c.c.) was boiled vigorously, and sodium (3·4 g.) added in one piece, the heating being continued until all the sodium had dissolved. The solution was cooled, water (15 c.c.) added, and the ethyl alcohol distilled off under diminished pressure (32 c.c. being collected). The residual, strongly alkaline liquid was extracted with ether; the extract, dried over potassium carbonate and distilled, gave the *carbinol* as a colourless viscous liquid (1·55 g., b. p. 122°/12 mm.) (Found: C, 63·0; H, 11·5. $C_6H_{13}ON$ requires C, 62·6; H, 11·3%). It solidified after several days and was hygroscopic. The *picrate* formed bright yellow, rectangular prisms, m. p. 120°, from alcohol (Found: C, 42·2; H, 4·75. $C_6H_{13}ON,C_6H_3O_7N_3$ requires C, 41·9; H, 4·7%).

bicyclo[1 : 2 : 2]*Aza-1-heptane.*—A solution of the carbinol (1·55 g.) in benzene (10 c.c.) was treated with phosphorus pentabromide (8·0 g.), and the mixture heated on the water-bath under reflux for 3 hours. The reddish-brown mixture was cooled, and a little crushed ice added, followed by excess of a suspension of sodium bicarbonate. The mixture was diluted with water (90 c.c.) and left at room temperature for several hours; potassium hydroxide solution (10 c.c. of 50%) was then added, and the solution warmed at 40° for 2 hours. It was steam-distilled, the distillate (50 c.c.) acidified with hydrochloric acid and evaporated to dryness, and the residue basified with potassium hydroxide solution (50%) and extracted several times with ether (30 c.c.). The ethereal extract, dried over potassium carbonate, was added to an alcoholic solution of picric acid (3 g.), whereupon the bright yellow, insoluble picrate of the bicyclic base separated, m. p. 271° (2·7 g.). The *picrate* was difficultly soluble in ethyl alcohol, easily soluble in warm acetone, and crystallised from alcohol–acetone in lemon-yellow needles, m. p. 274° (decomp.) (Found: C, 44·5; H, 4·4. $C_6H_{11}N,C_6H_3O_7N_3$ requires C, 44·2; H, 4·3%). The yield of the bicyclic base calculated from the amount of picrate obtained is 60% of the theoretical. The picrate was treated with a slight excess of potassium hydroxide solution (10%) and steam-distilled; the distillate (20 c.c.) was acidified with hydrochloric acid and evaporated to dryness, absolute alcohol (10 c.c.) added, and the solution again evaporated to dryness. The residue of the hydrochloride of the base was easily soluble in water, and crystallised from methyl alcohol in white rectangular prisms, which sublimed at 310° and decomposed at 350°.

The free base was obtained by dissolving the hydrochloride in a little water and treating it with an excess of solid potassium hydroxide with cooling. The oil which separated was taken up in ether and dried over solid potassium hydroxide, the ether removed in a vacuum at 10°, and the residual liquid distilled in a vacuum over sodium; a colourless, mobile liquid having a very penetrating, basic, herring-like odour was obtained (b. p. 130°/755 mm.) (Found: N, 14·3, 14·6. Calc. for $C_6H_{11}N$: N, 14·4%).

The *methiodide* crystallised from ethyl alcohol in white rectangular prisms, m. p. 320° (decomp.) (Found: C, 34·9; H, 5·9. $C_6H_{11}N,CH_3I$ requires C, 35·1; H, 6·0%). The *aurichloride* was difficultly soluble in water, and crystallised from aqueous alcohol in yellow prisms, m. p. 280° (decomp.) (Found: Au, 45·3; C, 17·1; H, 3·0. $C_6H_{11}N,HAuCl_4$ requires Au, 45·1; C, 16·5; H, 2·8%), and the *picrolonate* crystallised from acetone–alcohol in pale yellow rosettes of needles, m. p. 255° (decomp.) (Found: C, 53·1; H, 5·0. $C_6H_{11}N,C_{10}H_8O_5N_4$ requires C, 53·2; H, 5·3%).

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UNIVERSITY OF DURHAM, KING'S COLLEGE,
NEWCASTLE-UPON-TYNE. [*Received, August 4th, 1937.*]

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316. *A Relationship between β-Naphthylamine and Ethyl β-Aminocrotonate.*

By J. KENNER, W. H. RITCHIE, and R. L. WAIN.

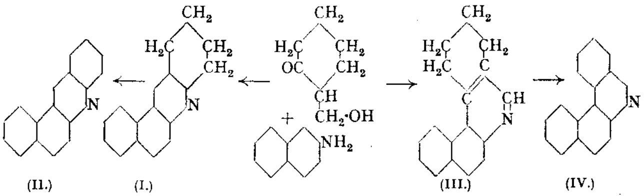
Extension of the recently described synthesis of 5 : 6 : 7 : 8-tetrahydrophenanthridine to β-naphthylamine unexpectedly yields two isomeric bases of the desired composition, and the same products are obtained from 1-bromo-β-naphthylamine. One of these furnishes β-naphthacridine on dehydrogenation, and is therefore the tetrahydro-β-naphthacridine. The isomer is doubtless the expected tetrahydro-

phenanthridine derivative, since the dehydrogenated base in concentrated sulphuric acid exhibits the blue fluorescence characteristic of phenanthridine bases.

This exceptional behaviour of β-naphthylamine is indicative of its specially close relationship to ethyl β-aminocrotonate, since the latter furnishes ethyl hexahydroquinaldine-3-carboxylate on condensation with 2-methylol*cyclo*hexanone.

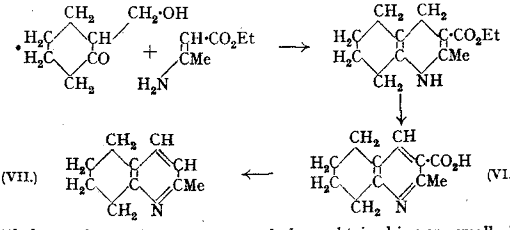
It was recently shown (Kenner, Ritchie, and Statham, this vol., p. 1169) that 5 : 6 : 7 : 8-tetrahydrophenanthridine and its derivatives resulted from the condensation of 2-methylol-*cyclo*hexanone with aromatic amines. From β-naphthylamine, however, two isomerides of the expected composition have been obtained. Furthermore, the same isomerides, though in smaller yield, resulted from the use of 1-bromo-β-naphthylamine in place of β-naphthylamine itself. Similarly, 3-bromo-β-naphthylamine furnished two isomeric bases, but each containing bromine. It was therefore apparent that in each case ring-closure involved the 1-position of the naphthalene nucleus. The suspicion that one of the two products in each case might be a tetrahydronaphthacridine (I) was readily confirmed, since one of the dehydrogenated bases exhibited the characteristic green fluorescence of acridine derivatives in concentrated sulphuric acid and proved to be identical with β-naphthacridine (II; Ullmann, *Annalen*, 1907, **355**, 350). Since the solution of its isomeride in sulphuric acid showed the usual blue fluorescence of phenanthridines, it was doubtless the expected β-naphthaphenanthridine (IV).

Some explanation of this remarkable differentiation of β-naphthylamine from the



(II.) (I.) (III.) (IV.)

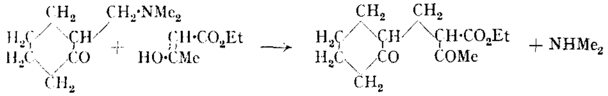
aromatic bases previously employed was revealed by a study of the reaction between the methylol*cyclo*hexanone and ethyl β-aminocrotonate. Besides ethyl dihydrolutidinedicarboxylate, doubtless arising from partial decomposition of the methylol into formaldehyde and *cyclo*hexanone, a basic product was isolated and readily characterised by its *picrate* and its *picrolonate*. The formation of quinaldine on dehydrogenation indicated that the base was *ethyl hexahydroquinaldine*-3-*carboxylate* (V), and this was confirmed by its hydrolysis and simultaneous oxidation by hydrochloric acid (cf. the similar behaviour of ethyl dihydrolutidinedicarboxylate) to tetrahydrobenzoquinaldine-3-carboxylic acid (VI) (Basu, *Annalen*, 1934, **512**, 131), from which tetrahydrobenzoquinaldine (VII) itself was obtained.



(V.) (VI.) (VII.)

This little-known base, which had previously been obtained in very small yield by the reduction of quinaldine and certain of its derivatives (v. Braun, Gmelin, and Schultheiss,

Ber., 1923, **56**, 1344; Tröger and Pahle, *J. pr. Chem.*, 1926, **112**, 221; Tröger and Ungar, *ibid.*, p. 243), has been conveniently prepared by the condensation of ethyl aminocrotonate with 2-hydroxymethylene*cyclo*hexanone (Basu, *loc. cit.*). This reaction is akin to that now described, as is also that of ethyl sodioacetoacetate with 2-dimethylamino*cyclo*hexanone (Mannich, Koch, and Borkowsky, *Ber.*, 1937, **70**, 355):



It would appear from these results that β-naphthylamine is intermediate in character between the various aromatic amines already studied and ethyl aminocrotonate. This conclusion obviously invites correlation with the views expressed by Mills and Nixon (J., 1930, 2580) and later workers, but before proceeding to this it is desirable to see what results are afforded by other amines when submitted to condensation with methylol*cyclo*hexanone.

EXPERIMENTAL.

Bases from β-Naphthylamine.—A mixture of picrates (19 g.) from 2-methylol*cyclo*hexanone (12·8 g.) and corresponding amounts of the other reactants (cf. Kenner, Ritchie, and Statham, *loc. cit.*) was obtained from the unacetylated portion of the basic products, b. p. 220—400°/20 mm. Extraction with boiling alcohol (2250 c.c.) for ¾ hour left 7·1 g. of almost pure, sparingly soluble *picrate*, m. p. 253—254° after crystallisation from a very large volume of alcohol (Found: N, 12·2. $C_{17}H_{15}N,C_6H_3O_7N_3$ requires N, 12·1%), from which the *tetrahydronaphthacridine*, m. p. 94—94·5° (Found: C, 87·4; H, 6·6; N, 6·0. $C_{17}H_{15}N$ requires C, 87·5; H, 6·4; N, 6·0%), dehydrogenated *base*, m. p. 106° (Found: C, 88·6; H, 4·8; N, 6·2. $C_{17}H_{11}N$ requires C, 89·1; H, 4·8; N, 6·1%), and its *picrate*, m. p. 247—248° (decomp.) (Found: N, 12·3. $C_{17}H_{11}N,C_6H_3O_7N_3$ requires N, 12·2%), were derived. The more soluble *picrate* (9·9 g.), m. p. 218—219° (decomp.) (Found: N, 12·2%), yielded a *tetrahydro-base*, m. p. 114—115° (Found: C, 87·4; H, 6·4; N, 6·0%), a dehydrogenated *base*, m. p. 127° (Found: C, 89·0; H, 4·9; N, 6·2%), and its *picrate*, m. p. 266—267° (decomp.) (Found: N, 12·3%). From a similar experiment with 1-bromo-β-naphthylamine, the methylol (12·8 g.) yielded a mixture (6·0 g.) from which bromine-free picrates, m. p.'s 246—249° (decomp.) (4·3 g.) and 213—215° (decomp.) (0·9 g.), and tetrahydro-bases, m. p.'s 94—95° and 111—113°, were prepared, and identified by direct comparison with those just described.

3-Bromo-β-naphthylamine.—The following series of compounds was very briefly described by Wynne (P., 1914, **30**, 204), but without experimental details or analyses. Doubtless it is for this reason that the relevant data have not been included in Beilstein's Handbuch.

A hot solution of 2-amino-3-naphthoic acid, m. p. 219—220° (22·4 g.), in hydrobromic acid (*d* 1·48; 36 c.c.) and water (150 c.c.) was rapidly cooled, and treated during 1 hour at 2—3° dropwise with a solution of sodium nitrite (8·4 g.) in water (20 c.c.). After 2 hours the solid diazonium salt was collected in an ice funnel, and added to a cold solution of cuprous bromide [from copper sulphate, 21·6 g.; potassium bromide, 10·8 g.; and hydrobromic acid (*d* 1·48), 36 c.c.]. The mixture, after being shaken and diluted with water, was heated at 100° to complete the reaction. Yield 28·2 g., m. p. 213—215°. For analysis, the brownish-red *2-bromo-3-naphthoic acid* was decolorised in glacial acetic acid solution by sulphurous acid and a trace of zinc dust, and then crystallised successively from formic acid and from alcohol; needles, m. p. 219—220° (Wynne, 220°) (Found: Br, 31·9; equiv., 250. $C_{10}H_6Br{\cdot}CO_2H$ requires Br, 31·9%; equiv., 251). The *methyl* ester was most conveniently prepared by treating a solution of the crude acid (6·3 g.) in methanol (25 c.c.) and dry ether (100 c.c.) with diazomethane, generated by slowly adding nitroso-β-methylamino*iso*butyl methyl ketone (8 c.c.) to a 3% solution of sodium benzyloxide in benzyl alcohol (10 c.c.) at 70° under 400 mm. pressure. After 12 hours, methyl alcohol and ether were removed from the solution under reduced pressure, and the ester removed by repeated extraction with light petroleum (b. p. 40—60°); lustrous needles, m. p. 66·5° (Wynne 67°) (Found: C, 54·3; H, 3·5. $C_{12}H_9O_2Br$ requires C, 54·4; H, 3·4%). A solution of the ester (4·6 g.) in methyl alcohol (25 c.c.), and hydrazine hydrate (6 g.) at 35° for 17 hours yielded the *hydrazide* (4·1 g.), m. p. 222° after recrystallisation from alcohol (Wynne 218°) (Found: C, 49·6; H, 3·5; N, 10·8. $C_{11}H_9ON_2Br$ requires C, 49·8; H, 3·4; N, 10·6%).

3-*Bromo*-2-*naphthylurethane* was formed when ethyl nitrite (1 g.) was added to a mixture of the suspended hydrazide (2·65 g.) in alcohol (25 c.c.) with a solution of hydrogen chloride (0·5 g.) in alcohol (5 c.c.), and the resulting solution was boiled under reflux; yield 2·2 g.; needles, m. p. 114° (Wynne, 114°) (Found: C, 52·9; H, 4·2; N, 5·0. $C_{13}H_{12}O_2NBr$ requires C, 53·1; H, 4·1; N, 4·8%). When the urethane (20 g.) was boiled with hydrobromic acid (*d* 1·48; 100 c.c.) under reflux, the oil gradually gave place to the crystalline hydrobromide of 3-*bromo*-β-*naphthylamine*, and by extracting this crude salt with ether (Soxhlet) any unchanged urethane was recovered. The base separated from alcohol in plates, m. p. 168—169° (Wynne 168°) (Found: C, 53·9; H, 3·8; N, 6·5. $C_{10}H_8NBr$ requires C, 54·1; H, 3·6; N, 6·3%). 2 : 3-*Dibromonaphthalene*, from the base under conditions similar to those applied to 2-amino-3-naphthoic acid, crystallised from light petroleum (b. p. 60—80°) in lustrous, rectangular plates, m. p. 140° (Wynne 140°) (Found: C, 41·8; H, 2·2. $C_{10}H_6Br_2$ requires C, 42·0; H, 2·1%).

The basic product from methylol*cyclo*hexanone (4·3 g.), 3-bromo-β-naphthylamine (13·4 g.), its hydrochloride (8·6 g.), hydrated stannic chloride (13·2 g.), and alcohol (25 c.c.) was extracted thrice with hot hydrobromic acid (25 c.c.; *d* 1·48) and the residue was then no longer sticky. The base from the liquors yielded 3·3 g. of picrate, from which two salts were separated by crystallisation from alcohol. The less soluble *picrate*, m. p. 206° (decomp.) (Found: N, 10·5. $C_{17}H_{14}NBr,C_6H_3O_7N_3$ requires N, 10·4%), yielded a *base*, m. p. 133° (Found: N, 4·5. $C_{17}H_{14}NBr$ requires N, 4·5%), whilst the more soluble *picrate*, m. p. 156—157° (decomp.) (Found: N, 10·3%), furnished a *base*, m. p. 145° (Found: N, 4·5%). The amount of material available was too small for further work, but the results establish the formation of two isomeric bromo-tetrahydro-bases in the reaction.

*Interaction of Ethyl β-Aminocrotonate with 2-Methylol*cyclo*hexanone.*—After the ester (400 g.) and the methylol (400 g.) had been heated together at 100° for 48 hours, ethyl dihydrolutidinedicarboxylate (202 g.; m. p. 182—184° from alcohol) was collected [Found: N, 6·0; *M* (Rast), 242. Calc. for $C_{13}H_{19}O_4N$: N, 5·5%; *M*, 253], and identified by conversion into ethyl lutidinedicarboxylate, m. p. 72°, with nitrous acid, and into 2 : 6-lutidine (picrate, m. p. 160—162°) by dehydrogenation with selenium at 340° for 12 hours. Each substance was identified by direct comparison with an authentic specimen. Ether extraction of a solution of the oily portion of the product in dilute sulphuric acid yielded a further small quantity (4 g.) of the above ester. The basic material recovered from the acid solution yielded a main fraction (141 g.), b. p. 187—192°/25 mm., and 78 g., b. p. 192—240°/25 mm. No definite substance was isolated from the latter, but the main fraction, b. p. 171—174·5°/18 mm. after further fractionation, was readily characterised by its *picrolonate*, light yellow needles from alcohol, m. p. 212—214° (Found: C, 56·7; H, 5·6; N, 14·4. $C_{13}H_{19}O_2N,C_{10}H_8O_5N_4$ requires C, 56·9; H, 5·6; N, 14·4%). The base was identified as *ethyl hexahydroquinaldine*-3-*carboxylate* by its conversion after 18 hours at 320° by selenium into quinaldine, b. p. 235—242°, picrate, m. p. 187—188·5°, methiodide, m. p. 194—195°, *picrolonate*, m. p. 231—232·5° (Found: N, 17·4. $C_{10}H_{19}N,C_{10}H_8O_5N_4$ requires N, 17·5%). Although unattacked by boiling aqueous or alcoholic potassium hydroxide solution (by contrast with ethyl tetrahydrobenzoquinaldinecarboxylate; Basu, *loc. cit.*), the hexahydro-base (15 g.) underwent hydrolysis by boiling hydrochloric acid (*d* 1·17; 200 c.c.) during 20 hours. The cooled, filtered solution was evaporated, and the aqueous solution of the residue rendered neutral to Congo-red paper. Evaporation to dryness, followed by extraction with alcohol, and concentration of the alcoholic solution, furnished tetrahydrobenzoquinaldinecarboxylic acid (9·5 g.), m. p. 230—231° (decomp.) (Found: N, 7·3. Calc. for $C_{11}H_{13}O_2N$: N, 7·3%), which did not express the m. p. of a sample of the acid prepared by Basu's method (*loc. cit.*). By distillation with 10 times its weight of soda lime, the acid was converted into tetrahydrobenzoquinaldine, b. p. 224—225°, picrate, m. p. 152—156° (Found: N, 14·9. Calc.: N, 14·9%) (Basu, *loc. cit.*, gives m. p. 157°), *picrolonate*, yellow prisms, m. p. 220° (Found: N, 16·9. $C_{10}H_{13}N,C_{10}H_8O_5N_4$ requires N, 17·0%). In a repetition of Basu's preparation of the carboxylic ester, no tarry product was formed if freshly prepared hydroxymethylene*cyclo*hexanone was employed, and the yield was 40%.

College of Technology, Manchester. [*Received, June 8th*, 1937.]

317. *Experiments on the Synthesis of Rotenone and its Derivatives. Part XIII.*

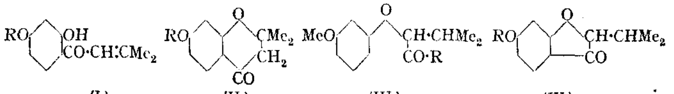
By Walter Bridge, Alfred J. Crocker, Thomas Cubin, and Alexander Robertson.

In a search for collateral evidence in support of the structure of 5 : 7-dihydroxy-chroman the properties of 7-hydroxy-2 : 2-dimethylchromanone and its derivatives have been studied. The synthesis of 6-methoxy-2-*iso*propyl-β-coumaranone by an absolute method confirms the structure of 7-hydroxy-2 : 2-dimethylchromanone and hence that of its reduction product 7-hydroxy-2 : 2-dimethylchroman, which has also been obtained by an *independent method*.

In forming 2-hydroxy-4-benzyloxyacetophenone on ozonolysis the behaviour of 7-hydroxy-2 : 2 : 4-*trimethylchromen*, which has been synthesised by two methods, is strictly analogous to that of the natural chromens xanthyletin and xanthoxyletin.

The experiments described in the present communication were undertaken as an extension of the investigations on the structure and properties of 5 : 7-dihydroxy-2 : 2-dimethyl-chroman (Part XII, this vol., p. 279) and related compounds, because (*a*) it seemed desirable to obtain collateral evidence in support of the structure of this chroman, and (*b*) the scission of the dihydro-γ-pyrone ring of 5 : 7-dimethoxy-2 : 2-dimethylchromanone with dilute alcoholic sodium hydroxide is of considerable interest in connexion with the stability of the chromanochromanone nucleus present in members of the rotenone series under similar conditions.

According to Arima (*J. Chem. Soc. Japan*, 1932, **53**, 715), 7-hydroxy-2 : 2-dimethyl-chromanone (II, R = H), prepared by the condensation of resorcinol and ββ-dimethyl-acryl chloride with aluminium chloride, has a red ferric reaction, but we have found that, although this is true of the partly purified material thus obtained, yet the pure compound is devoid of this property. This chromanone was also obtained when the ββ-dimethylacryl chloride was replaced by β-bromo*iso*valeryl chloride.



(I.) (II.) (III.) (IV.)

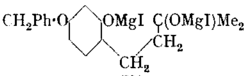
The properties of the chromanone (II, R = H), *viz.*, the negative ferric reaction and the formation of monoacyl and monoalkyl derivatives only, which are insoluble in aqueous sodium hydroxide and do not give ferric reactions, clearly distinguish this compound from the isomeric ketone (I, R = H) but not from the isomeric β-coumaranone (IV, R = H) (compare Arima and Okamoto, *J. Chem. Soc. Japan*, 1929, **50**, 344). The synthesis of the *methyl ether* (IV, R = Me) by an unambiguous method, however, serves to confirm the structure of the coumaranone (IV, R = H) and hence that of the chromanone (II, R = H).

The ether (IV, R = Me) was prepared according to the standard method of Stephen and co-workers (J., 1931, 896) : Interaction of the sodium salt of resorcinol monomethyl ether and ethyl α-bromo*iso*valerate gave rise to the ester (III, R = OEt) mixed with a small amount of ethyl ββ-dimethylacrylate. After hydrolysis of this mixture the *acid* (III, R = OH) was conveniently isolated and converted into the chloride (III, R = Cl), which on cyclisation with aluminium chloride in benzene gave an excellent yield of (IV, R = Me), identical with the methyl ether prepared from (IV, R = H).

Although we have been unable to isolate the by-product responsible for the ferric reaction given by the crude chromanone (II, R = H), it is clear that, since (IV, R = H) does not give a ferric reaction, this material must be the intermediate ketone (I, R = H). In this connexion it is of interest to note that, although the dihydro-γ-pyrone ring system of the 7-methoxy-2 : 2-dimethylchromanone (II, R = Me) undergoes scission with 5% alcoholic sodium ethoxide or with boiling 10% aqueous-alcoholic sodium hydroxide,

resulting in the formation of a product which is in all probability (I, R = Me) since it gives a strong ferric reaction, yet this ether appears to be more stable than the analogous 5 : 7-dimethoxy-2 : 2-dimethylchromanone (Part XII, *loc. cit.*) under comparable conditions. Like the latter compound, however, (II, R = Me) on treatment with semicarbazide acetate yields a *product*, $C_{13}H_{17}O_3N_3$, which is isomeric with the expected semicarbazone of (II, R = Me) but gives a strong ferric reaction and may be derived from the ketone (I, R = Me). Curiously enough, the semicarbazone obtained from 7-methoxychromanone has also been found to give a similar ferric reaction.

Attempts to reduce the coumaranone (IV, R = H) with the aid of amalgamated zinc by the method of Clemmensen gave rise to an amorphous product, whilst catalytic reduction of the diacetyl derivative (3 : 6-*diacetoxy-2-*iso*propylbenzofuran*) according to the procedure of Roll and Adams (*J. Amer. Chem. Soc.*, 1931, **53**, 3469) yielded a product which, after hydrolysis, was resolved into the coumaranone (IV, R = H) and a pleasant-smelling oil, insoluble in aqueous sodium hydroxide; the latter compound presumably arises by complete hydrogenation of the resorcinol nucleus. On the other hand, reduction of the chromanone (II, R = H) by Clemmensen's method furnished an excellent yield of the *chroman* (VI, R = H), but with hydrogen and a palladium–charcoal catalyst a product consisting of chroman, unchanged chromanone, and a small amount of alkali-insoluble material was obtained. Since in the latter procedure there is no reason to suspect that the dihydro-γ-pyrone ring opens, this result affords substantial evidence of the structure of (VI, R = H).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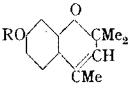
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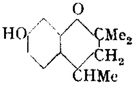
(VIII.)

The interaction of 7-benzyloxy-3 : 4-dihydrocoumarin and an excess of methylmagnesium iodide in warm benzene and decomposition of the product, presumably (V), in the usual manner gave rise to (VI, R = CH_2Ph) which on debenzylation furnished the chroman (VI, R = H), thus affording a new route to compounds of this type. Under similar conditions *7-benzyloxy-4-methylcoumarin* gave rise to the *benzyloxychromen* (VII, R = CH_2Ph) (cf. Houben, *Ber.*, 1904, **37**, 498; Heilbron and Hill, J., 1927, 2005), the structure of which clearly follows from its formation by the action of methylmagnesium iodide on *7-benzyloxy-2 : 2-dimethylchromanone* (II, R = CH_2Ph) and subsequent hydrolysis of the product. Catalytic hydrogenation of the *benzyl ether* (VII, R = CH_2Ph) with the aid of a palladium–charcoal catalyst was accompanied by removal of the benzyl group, and gave rise to the chroman (VIII) (isolated as the p-*nitrobenzoate*) which was identical with a specimen prepared by the hydrogenation of the *chromen* (VII, R = H) resulting from the debenzylation of (VI, R = CH_2Ph) by means of warm acetic acid containing hydrochloric acid.

In the investigations on the constitution of the chromeno-α-pyrones xanthyletin and xanthoxyletin (J., 1936, 627, 1828), it was found that degradation of the chromen system with ozone proceeded abnormally and, instead of the expected product formed by scission across the double bond in the 3 : 4-position and containing the same number of carbon atoms, an *o*-hydroxyaldehyde was obtained, in which respect the behaviour of these chromens appears to be analogous to that of a benzofuran system; *e.g.*, compare usneol (Schöpf and Heuck, *Annalen*, 1927, **459**, 233). In agreement with these results, ozonolysis of the authentic chromen (VII, R = CH_2Ph) has now been found to proceed in a similar manner, giving rise to 2-hydroxy-4-benzyloxyacetophenone.

EXPERIMENTAL.

7-Hydroxy-2 : 2-dimethylchromanone (II, R = H).—It was found advantageous to prepare this compound by the following modification of Arima's procedure (*loc. cit.*). Well-powdered aluminium chloride (25 g.) was gradually added to a solution of ββ-dimethylacryl chloride (9 g.) and resorcinol (8 g.) in nitrobenzene (100 c.c.) at room temperature, and 4 days later the

mixture was treated with ice and hydrochloric acid. The product and nitrobenzene were isolated with ether, the nitrobenzene removed with steam, and the chromanone (10·5 g.) purified by crystallisation from dilute alcohol and then from chloroform–light petroleum, forming colourless needles, m. p. 172°, which gave a negative ferric reaction. This compound (7 g.) was also obtained by the interaction of resorcinol (7·5 g.), β-bromo*iso*valeryl chloride (8 g.), and aluminium chloride (22 g.) in nitrobenzene (100 c.c.) under the same conditions.

Acetylation of the chromanone (0·5 g.) with pyridine (1 c.c.) and acetic anhydride (2 c.c.) at room temperature gave the *acetate* (0·55 g.), which formed needles, m. p. 91°, from light petroleum (b. p. 60—80°) (Found: C, 66·9; H, 5·9. $C_{13}H_{14}O_4$ requires C, 66·7; H, 6·0%).

Prepared by the interaction of the chromanone (1 g.) with *p*-nitrobenzoyl chloride (1·2 g.) in pyridine (15 c.c.) at 60°, the p-*nitrobenzoate* (1·1 g.) separated from alcohol in elongated, straw-coloured prisms, m. p. 137° (Found: N, 4·2. $C_{18}H_{15}O_6N$ requires N, 4·1%).

Methylation of 7-hydroxy-2 : 2-dimethylchromanone (3 g.) with methyl iodide (4 c.c.) and excess of potassium carbonate in boiling acetone (120 c.c.) in the course of 5 hours gave the methyl ether (II, R = Me) (3 g.), forming rectangular plates, m. p. 77°, from light petroleum (b. p. 40—60°); like the acetate and *p*-nitrobenzoate, this is insoluble in aqueous sodium hydroxide, and has a negative ferric reaction [Found: C, 70·1; H, 6·8; OMe, 15·8. Calc. for $C_{11}H_{11}O_2(OMe)$: C, 69·9; H, 6·8; OMe, 15·0%] (cf. Arima, *loc. cit.*). Treatment of this derivative with warm alcoholic 2 : 4-dinitrophenylhydrazine hydrochloride gave the 2 : 4-*dinitrophenylhydrazone*, which separated from ethyl acetate in slender red needles, m. p. 221° (Found: N, 14·4. $C_{18}H_{18}O_6N_4$ requires N, 14·5%).

Interaction of the methyl ether and semicarbazide acetate in the usual manner gave rise to a *product* which formed elongated prisms, m. p. 226° (decomp.), from alcohol, giving a red-brown coloration with alcoholic ferric chloride (Found: C, 59·4; H, 6·6; N, 15·8. $C_{13}H_{17}O_3N_3$ requires C, 59·3; H, 6·5; N, 16·0%). By means of warm alcoholic 2 : 4-dinitrophenylhydrazine hydrochloride this compound was converted into the 2 : 4-dinitrophenylhydrazone, m. p. and mixed m. p. 221°, after purification from ethyl acetate.

A mixture of the foregoing methyl ether (0·5 g.), veratraldehyde (0·5 g.), alcohol (4 c.c.), and 10% aqueous sodium hydroxide (3·5 c.c.) was gently refluxed for 20 minutes and diluted with water (50 c.c.). Crystallisation of the yellow precipitate, which gave a red ferric chloride reaction, from dilute alcohol finally gave a product in pale yellow plates, m. p. 80°, which had a negative ferric reaction and seemed to be the veratrylidene derivative but did not appear to be analytically pure although the m. p. remained unchanged after repeated purification (Found: C, 70·0; H, 6·5. Calc. for $C_{21}H_{22}O_5$: C, 71·2; H, 6·2%).

Acidification of the alkaline liquors left on removal of the solid gave a small amount of material having a red ferric reaction.

Attempts to prepare the veratrylidene derivative by condensation of the chromanone and veratraldehyde in acetic acid with hydrogen chloride gave rise to an amorphous product, m. p. 130—132°, after purification with the aid of alcohol. The crude material had a red ferric reaction.

On attempting to prepare the veratrylidene derivative of 7-methoxychromanone by condensation of the chromanone and veratraldehyde with boiling 10% aqueous-alcoholic sodium hydroxide, a resinous product having a strong ferric reaction was obtained, but when the reaction was carried out under the conditions employed by Pfeiffer and Grimmer (*Ber.*, 1917, **50**, 911) the required compound was obtained, m. p. 141°, identical with a specimen prepared by the hydrogen chloride–acetic acid method (Perkin, Ray, and Robinson, J., 1926, 946).

7-Hydroxy-2 : 2-dimethylchroman (VI, R = H).—(A) A mixture of 7-hydroxy-2 : 2-dimethylchromanone (2 g.), acetic acid (20 c.c.), and 18% hydrochloric acid (75 c.c.), containing amalgamated zinc dust (50 g.), was kept at room temperature for 24 hours, treated with 12% hydrochloric acid (20 c.c.), heated on the steam-bath for 1 hour, and then refluxed for 3 hours. The product was isolated with ether, and on distillation in a high vacuum gave the *chroman* (1·1 g.) as an almost colourless oil, b. p. 140—143°/0·1 mm., which slowly solidified and then separated from light petroleum (b. p. 40—60°) in colourless slender needles, m. p. 72° (Found: C, 74·2; H, 7·9. $C_{11}H_{14}O_2$ requires C, 74·2; H, 7·9%).

(B) Absorption of hydrogen by 7-hydroxy-2 : 2-dimethylchromanone (1 g.), dissolved in acetic acid (200 c.c.), containing a palladium–charcoal catalyst (from 0·2 g. of palladium chloride and 2 g. of charcoal), appeared to have ceased in about 10 hours. After the separation of the catalyst by filtration, the greater part of the acetic acid was removed in a vacuum, the residue neutralised with aqueous sodium bicarbonate, and the product isolated with ether and resolved into a small amount of an oily neutral fraction and a semi-solid phenolic fraction by means of

dilute aqueous sodium hydroxide. The latter material was extracted with boiling light petroleum, and the extract evaporated, leaving a very viscous oil from which 7-hydroxy-2 : 2-dimethylchroman was isolated by sublimation in a high vacuum (temperature of oil-bath, 110—115°), m. p. 71—72°, identical with the compound obtained by Clemmensen's method. The residue insoluble in light petroleum was found to consist of unchanged chromanone, m. p. and mixed m. p. 170—171°.

Interaction of the chroman (0·8 g.) and *p*-nitrobenzoyl chloride (1 g.) in pyridine (15 c.c.) at 60° for 6 days gave rise to the p-*nitrobenzoate* (1·2 g.), which formed colourless slender prisms, m. p. 126°, from alcohol (Found : N, 4·4. $C_{18}H_{17}O_5N$ requires N, 4·3%).

(C) In the preparation of 7-hydroxycoumarin for this work by the condensation of resorcinol and malic acid with sulphuric acid according to v. Pechmann (*Ber.*, 1884, **17**, 932), consistently poor yields were obtained. As the result of a large number of experiments in which the ratio of the reactants, the concentration of the sulphuric acid, and the temperature were varied, the following appeared to be the most satisfactory procedure :—An intimate mixture of resorcinol (3 g.), malic acid (2·46 g.), and concentrated sulphuric acid (6·1 c.c.) was heated in an oil-bath at 120° until the effervescence had ceased (about 1 hour), cooled, and treated with excess of crushed ice. The precipitated coumarin was purified by repeated crystallisation from dilute alcohol (charcoal) and obtained in pale pink prisms, m. p. 227—228° ; it was found that the crude product could be conveniently decolorised by leading a stream of sulphur dioxide into a warm concentrated alcoholic solution of the coumarin. Yield, 43% of the theoretical. Benzylation of 7-hydroxycoumarin (4 g.) was effected by means of benzyl bromide (5 c.c.) and potassium carbonate (7 g.) in boiling acetone (100 c.c.) in the course of 4—5 hours, and on isolation the *benzyl ether* separated from benzene in elongated prisms, m. p. 154° (Found : C, 76·1 ; H, 5·0. $C_{16}H_{12}O_3$ requires C, 76·2 ; H, 4·8%).

Hydrogenation of 7-hydroxycoumarin (3 g.), dissolved in a mixture of alcohol (10 c.c.) and 0·1*N*-aqueous sodium hydroxide (50 c.c.), containing an active palladium–charcoal catalyst, gave rise to β-2 : 4-dihydroxyphenylpropionic acid, m. p. 164—165° (decomp.), which on being kept at 130—135° for 2 hours was converted into 7-hydroxy-3 : 4-dihydrocoumarin, m. p. 132—133° after purification (cf. Späth and Klager, *Ber.*, 1933, **66**, 749 ; Langley and Adams, *J. Amer. Chem. Soc.*, 1922, **44**, 2320). Benzylation of this compound (4 g.) with benzyl bromide (7 c.c.) and excess of potassium carbonate in boiling acetone (50 c.c.) in the course of 4 hours gave the benzyl ether (5·8 g.) as a pale yellow oil, b. p. 220°/0·3 mm.

A solution of 7-benzyloxy-3 : 4-dihydrocoumarin (3 g.) in ether (20 c.c.) was added to methylmagnesium iodide (from 5·5 g. of methyl iodide and 0·86 g. of magnesium) in ether (25 c.c.), and the mixture refluxed for 1 hour. After isolation in the usual manner, the product was digested with dilute sodium hydroxide to remove traces of debenzylated material, and the alkali-insoluble fraction separated with ether and purified by distillation in a vacuum, giving 7-*benzyloxy*-2 : 2-*dimethylchroman* (VI, R = CH_2Ph) as an almost colourless oil (2 g.), b. p. 160—165°/0·4 mm. (Found : C, 80·6 ; H, 7·7. $C_{18}H_{20}O_2$ requires C, 80·6 ; H, 7·5%). A mixture of this compound (0·4 g.) and acetic acid (10 c.c.), containing concentrated hydrochloric acid (0·93 c.c.), was refluxed for 2 hours, diluted with water, and neutralised with sodium bicarbonate. A solution of the crude product in ether (50 c.c.) was extracted several times with 10% aqueous sodium hydroxide (5 c.c.), the combined extracts acidified with hydrochloric acid, and the resulting 7-hydroxy-2 : 2-dimethylchroman (0·11 g.) isolated with ether and purified by sublimation in a high vacuum and then by crystallisation from light petroleum (b. p. 40—60°), forming slender needles, m. p. 72°, identical with specimens prepared by methods (A) and (B) (Found : C, 74·2 ; H, 8·0%). Evaporation of the ethereal solution left on removal of the chroman by means of aqueous sodium hydroxide gave unchanged benzyl ether (0·17 g.).

Experiments on the debenzylation of the compound (0·5 g.) by means of hydrogen and an active palladium–charcoal catalyst gave rise to a mixture of 7-hydroxy-2 : 2-dimethylchroman and unchanged material.

3 : 6-*Diacetoxy*-2-iso*propylbenzofuran*.—6-Hydroxy-2-*iso*propyl-β-coumaranone (3 g.) (Arima and Okamoto, *J. Chem. Soc. Japan*, 1929, **50**, 344) was boiled with acetic anhydride (20 c.c.), containing sodium acetate (1·5 g.), for ½ hour, and after isolation the *diacetate* (3·5 g.) separated from light petroleum (b. p. 40—60°) in colourless elongated prisms, m. p. 56° [Found : C, 65·4 ; H, 5·8 ; Ac, 35·9. $C_{11}H_{10}O(OAc)_2$ requires C, 65·2 ; H, 5·8 ; Ac, 31·2%].

6-*Methoxy*-2-iso*propyl*-β-*coumaranone* (IV, R = Me).—(A) Methylation of 6-hydroxy-2-*iso*propyl-β-coumaranone (*loc. cit.*) (1·2 g.) with excess of methyl iodide and potassium carbonate in boiling acetone during 3 hours gave the *methyl ether*, which formed stout prisms (0·7 g.), m. p. 78°, from light petroleum (b. p. 40—60°) [Found : C, 70·0 ; H, 6·9 ; OMe, 15·3.

$C_{11}H_{11}O_2(OMe)$ requires C, 69·9; H, 6·8; OMe, 15·0%]. Mixed with the isomeric chromanone, m. p. 72°, it melted at 64—68°.

(B) The material obtained by the interaction of resorcinol monomethyl ether (12 g.) and ethyl α-bromo*iso*valerate (17 g.) in alcoholic sodium ethoxide (from 80 c.c. of alcohol and 2·1 g. of sodium) at room temperature for 14 hours and then on the water-bath for 6 hours was hydrolysed by being digested with 12% aqueous-alcoholic sodium hydroxide (60 c.c.) at 30—40°, the solution was acidified with hydrochloric acid, and the product isolated with ether and resolved by distillation in a vacuum into a little ββ-dimethylacrylic acid, resulting from the decomposition of ethyl α-bromo*iso*valerate in the course of the condensation, and *α-3-methoxyphenoxyisovaleric acid* (III, R = OH), b. p. 148—153°/·01 mm. [Found: OMe, 13·7. $C_{11}H_{13}O_3(OMe)$ requires OMe, 13·8%].

After the vigorous reaction between α-3-methoxyphenoxy*iso*valeric acid (6 g.) and phosphorus pentachloride (5·6 g.) had almost ceased, the mixture was heated at 40° for a few minutes and kept for 1 hour, and the phosphoryl chloride removed in a vacuum. To a solution of the residual acid chloride (III, R = Cl) in thiophen-free benzene (50 c.c.), maintained at 0°, powdered aluminium chloride (3·5 g.) was added in the course of ¾ hour, the reaction mixture kept at room temperature for 3 hours, and the product isolated in the usual manner and distilled in a vacuum, giving a main fraction (3·5 g.), b. p. 120—125°/0·1 mm., as a mobile oil. This material, which rapidly became dark red, was digested with 1% aqueous sodium hydroxide, and on isolation with ether the alkali-insoluble, colourless oil solidified and then separated from light petroleum (b. p. 40—60°) in colourless stout prisms, m. p. 78°, identical with the material prepared by method (A) (Found: C, 69·8; H, 6·9%). The colour which developed in the partly purified material appeared to be due to traces of an unstable alkali-soluble impurity.

Semicarbazone of 7-Methoxychromanone.—Prepared in the usual manner, this compound was found to melt at 231° (Perkin, Ray, and Robinson, J., 1926, 946, give m. p. 222°) (Found: N, 17·8. Calc. for $C_{11}H_{13}O_3N_3$: N, 17·9%). With alcoholic ferric chloride it gave a red-brown coloration.

7-Hydroxy-2 : 2 : 4-trimethyl-Δ^3-chromen (VII, R = H).—(A) Benzylation of 7-hydroxy-4-methylcoumarin (Robertson and co-workers, J., 1931, 1257) (44 g.) was effected with benzyl bromide (50 c.c.) and potassium carbonate (70 g.) in boiling acetone (630 c.c.) in the course of 10 hours, and on isolation the *benzyl ether* separated from alcohol in flat rhombic prisms, m. p. 117·5° (Found: C, 76·4; H, 5·3. $C_{17}H_{14}O_3$ requires C, 76·7; H, 5·3%). Methylmagnesium iodide (from 5·14 g. of metal and 30 g. of methyl iodide) was prepared in ether (150 c.c.), and the solvent evaporated. A solution of 7-benzyloxy-4-methylcoumarin (19 g.) in benzene (250 c.c.) was then introduced, and the mixture refluxed for 5 hours. After isolation in the usual manner, the product was distilled in a vacuum, yielding a main fraction, b. p. 166—170°/0·25 mm., which solidified and then on repeated crystallisation from the alcohol gave *7-benzyloxy-2 : 2 : 4-trimethyl-Δ^3-chromen* (VII, R = CH_2Ph) in colourless slender prisms, m. p. 58° (Found: C, 81·7; H, 7·3. $C_{19}H_{20}O_2$ requires C, 81·4; H, 7·1%). Yield, 80% of the theoretical.

A solution of the benzyl ether (3 g.) in acetic acid (75 c.c.), containing concentrated hydrochloric acid (7 c.c.), was heated on the water-bath for 1½ hours, and the resulting green mixture poured into water (1·5 l.). Next day, the crystalline precipitate of *7-hydroxy-2 : 2 : 4-trimethyl-Δ^3-chromen* was collected and purified by sublimation in a high vacuum and then by recrystallisation from light petroleum (b. p. 80—100°), forming colourless elongated prisms, m. p. 130°, soluble in alcohol or benzene (Found: C, 75·8; H, 7·4. $C_{12}H_{14}O_2$ requires C, 75·8; H, 7·4%).

(B) *7-Benzyloxy-2 : 2-dimethylchromanone* (II, R = CH_2Ph) was prepared by benzylation of 7-hydroxy-2 : 2-dimethylchromanone (1 g.) with benzyl bromide (1·1 c.c.) and excess of potassium carbonate in boiling acetone (25 c.c.) in the course of 5 hours, and on isolation was purified by distillation in a vacuum, b. p. 172—174°/0·3 mm., and then by crystallisation from light petroleum (b. p. 80—100°), forming colourless prisms, m. p. 73° (Found: C, 76·6; H, 6·4. $C_{18}H_{18}O_3$ requires C, 76·6; H, 6·4%). A mixture of this compound (1 mol.), methylmagnesium iodide (1·25 mol.), and ether was refluxed for 6 hours and, after isolation in the usual manner, the product was distilled in a high vacuum. On being triturated with a little light petroleum (b. p. 40—60°), the semi-solid distillate gave a small amount of crystalline material which separated from dilute alcohol in plates, m. p. 57°, undepressed by admixture with an authentic specimen of 7-benzyloxy-2 : 2 : 4-trimethyl-Δ^3-chromen, m. p. 58°. Attempts to increase the yield of this compound by varying the conditions of the reaction were entirely unsuccessful; when the Grignard reaction was carried out in toluene on the water-bath for 5 hours the product consisted mainly of a crystalline compound, m. p. 163°, which was not further investigated.

7-Hydroxy-2 : 2 : 4-trimethylchroman (VIII).—Hydrogenation of 7-benzyloxy-2 : 2 : 4-tri-

methyl-Δ^3-chromen (5 g.), dissolved in alcohol (275 c.c.), with hydrogen (950 c.c. absorbed) and a palladium–charcoal catalyst (from 2 g. of charcoal and 0·2 g. of palladium chloride) was accompanied by removal of the benzyl group, and the resulting hydroxy-chroman was obtained as a very viscous, almost colourless liquid, insoluble in water and having a negative ferric reaction, which has not been crystallised. On treatment with an excess of *p*-nitrobenzoyl chloride dissolved in pyridine at room temperature for several days and then at 60—65° for 3 hours, this material gave an almost theoretical yield of the p-*nitrobenzoate*, which separated from alcohol in pale straw-coloured, slender needles, m. p. 137° (Found: C, 67·0; H, 5·7. $C_{19}H_{19}O_5N$ requires C, 66·9; H, 5·6%). 8% Aqueous sodium hydroxide (20 c.c.) was added to a solution of this ester (3·5 g.) in hot alcohol (40 c.c.), and the mixture kept for ½ hour. On isolation, the recovered hydroxychroman was obtained as a very viscous liquid which, after being purified by distillation in a high vacuum, did not solidify.

On hydrogenation of 7-hydroxy-2 : 2 : 4-trimethyl-Δ^3-chromen (0·75 g.), dissolved in alcohol (100 c.c.), with the aid of a platinum catalyst (0·1 g.), the chroman was obtained as a viscous liquid, which was characterised by formation of the *p*-nitrobenzoate, m. p. and mixed m. p. 137°, after crystallisation from alcohol.

Ozonolysis of 7-Benzyloxy-2 : 2 : 4-trimethyl-Δ^3-chromen.—A stream of ozone and oxygen (rate approx. 50—60 c.c./min.) was led into a solution of the chromen (2 g.) in chloroform (75 c.c.) for 1½ hours, the solvent removed, and the residue hydrolysed with water. Distillation of the product in a high vacuum gave a solid, m. p. about 94°, which on crystallisation from alcohol yielded 2-hydroxy-4-benzyloxyacetophenone, m. p. 105°, identified by comparison with an authentic specimen, m. p. 105—106°, prepared by partial benzylation of resacetophenone (E.P. 377464; *Centr.*, 1932, 2, 2485, gives m. p. 105—106° but Venkataraman and co-workers, J., 1934, 1766, give m. p. 111°).

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UNIVERSITY OF LIVERPOOL. [*Received, July 10th*, 1937.]

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318. *Experiments on the Synthesis of Rotenone and its Derivatives. Part XIV. The Structure of Toxicarol.*

By STEPHEN W. GEORGE and ALEXANDER ROBERTSON.

By the stepwise degradation of the methyl ether of dehydrodihydrotoxicarolic acid, derric acid and 5-hydroxy-7-methoxy-2 : 2-dimethylchroman have been isolated. From this result in conjunction with the established structure of dihydrotoxicarolic acid, structures for dehydrodihydro-, dehydro-, and dihydro-toxicarol, toxicarol, and dihydrodeoxytoxicarol have been deduced.

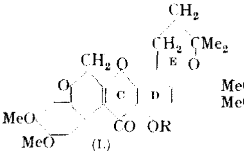
The syntheses of the reference compounds, 5-hydroxy-7-methoxy- and 7-hydroxy-5-methoxy-2 : 2-dimethylchroman, by way of the corresponding chromanones are described.

In connexion with preliminary attempts on the synthesis of dehydrodihydrotoxicarol the preparation of *allo*dihydrotoxicarolic acid and of 5 : 7-dihydroxychromeno-(3′ : 4′ : 2 : 3)-chromone is described.

FROM experiments on the methylation of dehydrodihydrotoxicarol and the degradation of the resulting *methyl ether* described in the present communication, evidence has been obtained enabling us to make a decision between the alternative formulæ which have been deduced for toxicarol, dihydro-, dehydro- and dehydrodihydro-toxicarol severally from the established structure of dihydrotoxicarolic acid (Part V, J., 1935, 681; Part XII, this vol., p. 279). Dehydrodihydrotoxicarol and not toxicarol or dihydrotoxicarol was chosen as the starting point of the investigation because with the latter compounds, not only is there a possibility of complications arising from the enolisation of the carbonyl group during the methylation process (toxicarol and dihydrotoxicarol yield *O*-diacetyl derivatives), but in the presence of alkaline reagents the stability of the chromanochromanone system is uncertain. Moreover, with toxicarol the instability of the 2 : 2-dimethyl-

Δ^3-chromen residue in the presence of hot aqueous-alcoholic sodium or potassium hydroxide (cf. Part V, *loc. cit.*) is an additional complication.

Although attempts to methylate dehydrodihydrotoxicarol by prolonged treatment with methyl iodide and potassium carbonate in boiling acetone were unsuccessful, the replacement of the iodide by methyl sulphate resulted in a satisfactory yield of the methyl ether; the same product was obtained when the alkylation was effected with methyl iodide and silver oxide in warm anisole. The properties, including the negative ferric reaction, of this substance clearly show that it is an ether and not a *C*-methyl derivative. On hydrolysis with aqueous-alcoholic sodium hydroxide it gave rise to O-*methyldihydrotoxicarolic acid* which, on the basis of the structure of dihydrotoxicarolic acid (II, R = H), can have either formula (II, R = Me) or (V), depending on whether the parent chromenochromone has the angular (I, R = Me) or the linear structure (IV, R = Me) with reference to rings C, D, and E.



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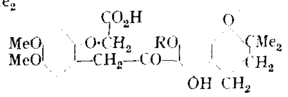

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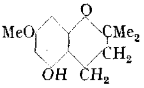

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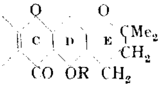
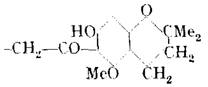
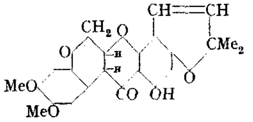


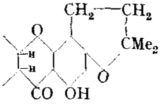


(V.)

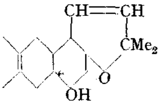
Fission of *O*-methyldihydrotoxicarolic acid by means of hot concentrated potassium hydroxide furnished derric acid and the liquid *5-hydroxy-7-methoxy-2 : 2-dimethylchroman* (III), which was conveniently characterised by formation of the distinctive yellow p-*nitrobenzoate*, identical with a specimen obtained from the synthetical chroman methyl ether. The production of the ether (III) in this manner clearly proves that *O*-methyldihydrotoxicarolic acid must have the structure (II, R = Me), a result which is possible only if *O*-methyldehydrodihydrotoxicarol has formula (I, R = Me). Hence dehydrodihydrotoxicarol is represented by the expression (I, R = H). In this connexion it may be noted that the relative positions of the carbonyl and hydroxyl groups in dihydrotoxicarolic acid have been deduced from the properties of dehydrodihydrotoxicarol (Part V, *loc. cit.*; cf. Clark, *J. Amer. Chem. Soc.*, 1932, **54**, 2537), but the formation of the 5-hydroxy-7-



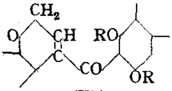
(VI.)



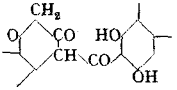
(VII.)



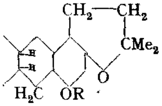
(VIII.)



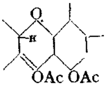
(IX.)



(X.)



(XI.)



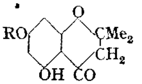
(XII.)

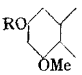
methoxy-2 : 2-dimethylchroman (III) by degradation of *O*-methyldehydrodihydrotoxicarol now affords independent proof that this acid has the structure (II, R = H) and not the

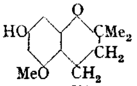
alternative (XVI, R = H). The latter structure would imply that dehydrodihydrotoxicarol has formula (XVII), the methyl ether of which on degradation would give rise finally to (XV) and not to (III).

In the formation of dehydro-compounds of the toxicarol series, *i.e.*, a change from the chromanochromanone to the chromenochromone type, according to standard procedures there is no reason to suppose that the former system undergoes scission with the production of intermediate types, *e.g.*, (IX, R = H) and (X), capable of undergoing cyclisation in two ways and thus resulting in the formation of products having the structure type (I) and (IV), a mechanism by which angular dehydro-derivatives, type (I), could arise from the parent chromanochromanones (toxicarol and dihydrotoxicarol) having the linear structure with respect to rings C, D, and E. This view finds ample support in the behaviour of dehydrotoxicarol on hydrogenation. With a platinum catalyst this compound gives dihydrotoxicarol, identical with that obtained directly from toxicarol (Clark, *J. Amer. Chem. Soc.*, 1931, **53**, 2264), whilst with a palladium-charcoal catalyst there is formed dehydrodihydrotoxicarol (see p. 1540) which can be subsequently converted into dihydrotoxicarol by means of a platinum catalyst. Consequently, it is clear that toxicarol, dihydrotoxicarol, and dehydrotoxicarol possess the same angular structure with respect to rings C, D, and E as is present in dehydrodihydrotoxicarol (I, R = H) and therefore may be represented by formulæ (VI), (VII), and (VIII) respectively. Thus the angular structure of toxicarol and its derivatives is the same as that obtaining in rotenone, deguelin, and tephrosin, and by analogy it seems probable that sumatrol may be similarly constituted (cf. this vol., p. 497). The possibility that toxicarol and its dihydro-derivative normally exist in the isomeric form, type (IX, R = H), analogous to a chalkone derived from a flavanone, is excluded because on hydrogenation a substance having this structure would be expected to give rise to an analogue of dihydrorotenol (Butendandt, *Annalen*, 1928, **464**, 253) by saturation of the ethylenic linkage. Further, although on acetylation toxicarol gives rise to an *O*-diacetyl derivative due to the enolisation of the carbonyl group, direct evidence for which has now been secured by the formation of an *oxime*, this diacetate is represented by formula type (XII) and not by (IX, R = Ac), a structure which, moreover, appears to be excluded by its behaviour on catalytic reduction. Under specific conditions (Clark, *J. Amer. Chem. Soc.*, 1931, **53**, 2264; cf. Part VIII, J., 1936, 212) *O*-diacetyltoxicarol is converted into a mixture of *O*-diacetyldihydrotoxicarol, type (XII), and *O*-acetyldihydrodeoxytoxicarol. The latter substance cannot be further hydrogenated, or acetylated to a diacetyl derivative, and on deacetylation yields dihydrodeoxytoxicarol which is devoid of a carbonyl group and does not give a ferric reaction. On account of their properties and relationship to toxicarol, it appears reasonably certain that dihydrodeoxytoxicarol and its acetate are represented by formula (XI, R = H) and (XI, R = Ac) respectively.

The authentic 5-hydroxy-7-methoxy-2 : 2-dimethylchroman (III) required for the present work was prepared by the partial methylation of the chromanone (XIII, R = H) and subsequent reduction of the resulting *methyl ether* (XIII, R = Me) by Clemmensen's method. Although the chroman (III) has been isolated as a viscous liquid which has not so far solidified, it was conveniently characterised by formation of the well-crystallised *p*-nitrobenzoate.


(XIII.)


(XIV.)

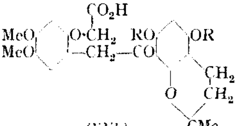

(XV.)

The orientation of (XIII, R = Me), and consequently that of (III), follows from the fact that, owing to chelation of the carbonyl and hydroxyl groups at the 4- and the 5-position, compounds of the type (XIII, R = H) are preferentially alkylated at the *p*-position to the carbonyl group. In agreement with the structure (XIII, R = Me), the ether is sparingly soluble in dilute aqueous sodium hydroxide and gives a strong ferric reaction.

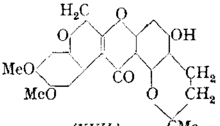
In order to obtain confirmatory evidence of the orientation of (III) the isomeric *ether*

(XV) was synthesised. Benzylation of 5 : 7-dihydroxy-2 : 2-dimethylchromanone gave rise to the *benzyl ether* (XIII, R = CH_2Ph), the properties of which are similar to those of the corresponding methyl ether (XIII, R = Me) and therefore determine its orientation. Methylation of (XIII, R = CH_2Ph) gave rise to (XIV, R = CH_2Ph), which on debenzylation by reductive fission with hydrogen and a palladium–charcoal catalyst furnished *7-hydroxy-5-methoxy-2 : 2-dimethylchromanone* (XIV, R = H). On reduction according to the method of Clemmensen, this compound yielded the *chroman* (XV), and, since the structure of the latter ether has been independently confirmed in these laboratories (private communication from Dr. T. S. Subramaniam) that of the isomeride (III) is conclusively established.

In the course of attempts to synthesise dehydrodihydrotoxicarol by application of the standard chromenochromone synthesis (Part III, J., 1933, 489), methyl 2-cyanomethyl-4 : 5-dimethoxyphenoxyacetate was condensed with 5 : 7-dihydroxy-2 : 2-dimethylchroman according to the method of Hoesch, but on hydrolysis of the resulting viscous oil the only crystalline product obtained was an acid which, since it is isomeric and not identical with dihydrotoxicarolic acid, must have the structure (XVI, R = H). The orientation ascribed to this compound, which we have named allo*dihydrotoxicarolic acid*, is in agreement with the fact that application of the Gattermann reaction to 5 : 7-dihydroxy-2 : 2-dimethylchroman yields only the 8-formyl derivative (this vol., p. 286).

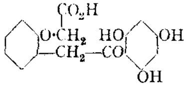


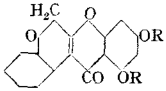
(XVI.)



(XVII.)

(XVIII.)





(XIX.)

By cyclisation of the acid (XVI, R = H) with boiling acetic anhydride containing sodium acetate, it was hoped to obtain the acetate of *allo*dehydrodihydrotoxicarol (XVII), but the only product which we were able to isolate from the reaction mixture appears to be a *hydrate* of O-diacetyl*allo*dihydrotoxicarolic acid (XVI, R = Ac), which on deacetylation with warm alcoholic hydrochloric acid regenerated the parent acid.

In view of the negative results obtained in attempting the cyclisation of the acid (XVI, R = H) and of 4 : 5-dimethoxyphenoxyacetic acid-2-phloracetophenone (Part V, *loc. cit.*), we investigated the cyclisation of the analogous *keto-acid* (XVIII), which was obtained in a satisfactory yield by the condensation of methyl 2-cyanomethylphenoxyacetate and phloroglucinol according to the standard procedure. On being boiled with acetic anhydride and sodium acetate, this compound gave rise to a small yield of the *diacetate* (XIX, R = Ac), which on deacetylation in the usual manner furnished the *chromenochromone* (XIX, R = H), and in consequence of this result we are re-investigating the cyclisation of 4 : 5-dimethoxyphenoxyacetic acid-2-phloracetophenone and related compounds. In connexion with these experiments it is of interest to note that, whereas according to Clark (*loc. cit.*) cyclisation of dihydrotoxicarolic acid (II, R = H) gives only O-acetyldehydrodihydrotoxicarol (I, R = Ac), it would normally be expected that this reaction would also yield the isomeride (IV, R = Ac). In our experiments on the conversion of dihydrotoxicarolic acid (II, R = H) into dehydrodihydrotoxicarol (I, R = H), we have found that, in addition to (I, R = Ac), the reaction mixture contains a considerable quantity of acidic material having a negative ferric reaction (presumably the diacetate of dihydrotoxicarolic acid) and a resinous residue from which a small amount of crystalline neutral product was obtained when it was treated with methyl-alcoholic sodium hydroxide. This

substance, which does not appear to be identical with (I, R = H), may possibly be *iso*-dehydrodihydrotoxicarol (IV, R = H), but owing to lack of material we have been unable to make a detailed examination of it.

EXPERIMENTAL.

5-Hydroxy-7-methoxy-2 : 2-dimethylchroman (III).—A mixture of 5 : 7-dihydroxy-2 : 2-dimethylchromanone (Part XII, *loc. cit.*) (2 g.), methyl iodide (0·5 c.c.), potassium carbonate (4 g.), and acetone (100 c.c.) was heated on the steam-bath for 3 hours; after 1½ hours more iodide (0·5 c.c.) and more carbonate (2 g.) were added. On isolation, the product was found to consist of almost pure *5-hydroxy-7-methoxy-2 : 2-dimethylchromanone* (XIII, R = Me), which separated from dilute alcohol in thick needles, m. p. 65—66° [Found : C, 65·0; H, 6·2; OMe, 15·0. $C_{11}H_{11}O_3(OMe)$ requires C, 64·9; H, 6·3; OMe, 14·0%]. This compound, which is soluble in warm acetic acid or benzene and sparingly soluble in light petroleum or 2% aqueous sodium hydroxide, gives a bright red coloration with alcoholic ferric chloride. The 2 : 4-*dinitrcphenylhydrazone* formed squat, blood-red prisms, m. p. 254°, from hot ethyl acetate (Found : N, 13·8. $C_{18}H_{18}O_7N_4$ requires N, 13·9%).

A mixture of the chromanone methyl ether (2 g.), amalgamated zinc dust (80 g.), alcohol (20 c.c.), concentrated hydrochloric acid (34 c.c.), and water (46 c.c.) was kept at room temperature for 2 days and, after the addition of 12% hydrochloric acid (20 c.c.), was heated on the water-bath for 1 hour and then refluxed for 6 hours (more acid, 20 c.c., was added). On being isolated with ether, the resulting *chroman* was purified by distillation in a vacuum and obtained as a viscous, pale reddish-brown oil (0·9 g.), b. p. 125—128°/0·4 mm., which has not been induced to crystallise [Found : OMe, 14·8. $C_{11}H_{13}O_2(OMe)$ requires OMe, 14·9%]. It is soluble in 2% aqueous sodium hydroxide and does not give a ferric reaction. Interaction of this compound (0·5 g.) with *p*-nitrobenzoyl chloride (0·6 g.) in pyridine (5 c.c.) at about 50° for several days gave rise to the p-*nitrobenzoate* (0·8 g.), which was separated from a little *p*-nitrobenzoic acid by means of aqueous sodium bicarbonate and then crystallised from 95% alcohol (charcoal), forming characteristic, squat, yellow prisms, m. p. 122°, which retained their colour after repeated purification (charcoal) (Found : C, 63·8; H, 5·4; N, 4·1. $C_{19}H_{19}O_6N$ requires C, 63·9; H, 5·3; N, 3·9%).

7-Benzyloxy-5-methoxy-2 : 2-dimethylchromanone (XIV, R = CH_2Ph).—Benzylation of 5 : 7-dihydroxy-2 : 2-dimethylchromanone (2 g.) by means of benzyl bromide (1·4 c.c., added in two portions) and excess of potassium carbonate in boiling acetone (100 c.c.) in the course of 3 hours gave rise to *5-hydroxy-7-benzyloxy-2 : 2-dimethylchromanone* (XIII, R = CH_2Ph) (2·2 g.), which separated from alcohol in thick colourless rods, m. p. 134°, giving a reddish-brown coloration with alcoholic ferric chloride (Found : C, 72·5; H, 6·1. $C_{18}H_{18}O_4$ requires C, 72·5; H, 6·0%). The 2 : 4-*dinitrophenylhydrazone* formed deep red rods, m. p. 242°, from hot alcohol (Found : N, 11·8. $C_{24}H_{22}O_7N_4$ requires N, 11·7%).

Methylation of the benzyl ether (2 g.) with excess of methyl iodide and potassium carbonate in boiling acetone (100 c.c.) for 6 hours yielded *7-benzyloxy-5-methoxy-2 : 2-dimethylchromanone*, which separated from aqueous alcohol as a *monohydrate* in colourless elongated, slender rods, m. p. 81—82°, insoluble in aqueous sodium hydroxide and having a negative ferric reaction [Found : C, 69·1; H, 6·6; OMe, 9·1. $C_{18}H_{17}O_3(OMe),H_2O$ requires C, 69·1; H, 6·7; OMe, 9·4%]. This compound, which is readily soluble in alcohol or ethyl acetate, gave a 2 : 4-*dinitrophenylhydrazone*, forming slender red needles, m. p. 215°, from ethyl acetate (Found : N, 11·3. $C_{25}H_{24}O_7N_4$ requires N, 11·4%). The *anhydrous* chromanone, which was obtained by drying the hydrated variety over phosphoric oxide in a vacuum, separated from light petroleum in hexagonal prisms, m. p. 111° [Found: C, 73·1; H, 6·5; OMe, 10·3. $C_{18}H_{17}O_3(OMe)$ requires C, 73·1; H, 6·4; OMe, 9·9%].

7-Hydroxy-5-methoxy-2 : 2-dimethylchromanone (XIV, R = H).—Debenzylation of 7-benzyloxy-5-methoxy-2 : 2-dimethylchromanone (5 g.), dissolved in acetic acid (300 c.c.), was effected with hydrogen (approx. 450 c.c. absorbed) and a palladium–charcoal catalyst (from 2 g. of charcoal and 0·2 g. of palladium chloride) in 2 hours. After the separation of the catalyst, the greater part of the solvent was distilled, the residue was diluted with water and neutralised with sodium bicarbonate, and the *chromanone* (3·0 g.) was isolated with ether. Crystallised from 95% alcohol, it formed colourless, elongated rectangular prisms, m. p. 208—209° (Found : C, 64·7; H, 6·3. $C_{12}H_{14}O_4$ requires C, 64·9; H, 6·3%). The 2 : 4-*dinitrophenylhydrazone* separated from hot ethyl acetate in short, dark red rods, m. p. 275° (decomp.) (Found : N, 14·0. $C_{18}H_{18}O_7N_4$ requires N, 13·9%).

7-Hydroxy-5-methoxy-2 : 2-dimethylchroman (XV).—A mixture of 7-hydroxy-5-methoxy 2 : 2-dimethylchromanone (2 g.), alcohol (20 c.c.), 15% hydrochloric acid (100 c.c.), and amalgamated zinc dust (80 g.) was kept for 2 days, treated with 12% hydrochloric acid (20 c.c.), heated on the steam-bath for 1 hour, and after the addition of more 12% hydrochloric acid (20 c.c.) boiled for 6 hours. On isolation with ether, the *chroman* (1·3 g.) crystallised from light petroleum (b. p. 80—100°) in short rectangular prisms, m. p. 103—104°, readily soluble in aqueous sodium hydroxide and having a negative ferric reaction [Found: C, 69·3; H, 7·8; OMe, 15·0. $C_{11}H_{13}O_2(OMe)$ requires C, 69·2; H, 7·7; OMe, 14·9%]. Interaction of the chroman (0·3 g.) and *p*-nitrobenzoyl chloride (0·4 g.) in pyridine (10 c.c.) at 50—60° for several days gave the p-*nitrobenzoate* (0·4 g.), which formed almost colourless elongated rods, m. p. 143°, from 95% alcohol (Found: N, 4·0. $C_{19}O_{19}O_6N$ requires N, 3·9%).

[With T. S. SUBRAMANIAM.] *Condensation of Phloroglucinol Monomethyl Ether and ββ-Dimethylacryl Chloride.*—To a solution of the ether (12 g.) in nitrobenzene containing aluminium chloride (14 g.), ββ-dimethylacryl chloride (Part XII, *loc. cit.*) (from 10 g. of the acid) was added during 1 hour, and 7 days later the reaction mixture was treated with ice (300 g.) and hydrochloric acid (40 c.c.) and thoroughly extracted with ether. After being washed with dilute hydrochloric acid and then with aqueous sodium bicarbonate, the combined extracts were evaporated, and the nitrobenzene distilled by means of steam. After the nitrobenzene had been removed, a quantity of solid separated from the subsequent aqueous distillate, and on recrystallisation from dilute alcohol this gave 5-hydroxy-7-methoxy-2 : 2-dimethylchromanone in elongated slender prisms (0·9 g.), m. p. 63—64°, identical with a specimen prepared by methylation of 5 : 7-dihydroxy-2 : 2-dimethylchromanone.

After the separation of 5-hydroxy-7-methoxy-2 : 2-dimethylchromanone, the residual hot aqueous liquors were decanted from the insoluble resinous material, and on being kept for several weeks gradually deposited a small amount of 7-hydroxy-5-methoxy-2 : 2-dimethylchromanone, which formed colourless prisms (0·2 g.), m. p. and mixed m. p. 209—210°, from alcohol.

Toxicarol Oxime.—A mixture of toxicarol (0·5 g.), hydroxylamine hydrochloride (0·5 g.), and pyridine (5 c.c.) was heated on the water-bath for 7—8 hours and then treated with ice-water. Crystallisation of the precipitated product (0·4 g.) from 50% alcohol and then from 95% alcohol gave the *oxime* in colourless irregular plates, m. p. 236—237° (Found: C, 65·0; H, 5·6; N, 3·3. $C_{23}H_{23}O_7N$ requires C, 65·0; H, 5·5; N, 3·3%).

Dehydrodihydrotoxicarol Methyl Ether (I, R = Me).—It has been found that, whereas on hydrogenation with a platinum catalyst dehydrotoxicarol is converted into dihydrotoxicarol (Clark, *J. Amer. Chem. Soc.*, 1931, **53**, 2268), yet when a palladium–charcoal catalyst is employed dehydrodihydrotoxicarol is obtained. Hydrogenation of dehydrotoxicarol (Clark, *loc. cit.*) (1 g.), dissolved in acetic acid (500 c.c.), with a palladium–charcoal catalyst (from 2 g. of charcoal and 0·2 g. of palladium chloride) and hydrogen (approx. 130 c.c. absorbed) at atmospheric pressure was complete in about 35 minutes. The filtered solution was evaporated in a vacuum, and the residual dehydrodihydrotoxicarol crystallised from methyl alcohol–chloroform, forming elongated yellow rods, m. p. 259°, identical with a specimen prepared from dihydrotoxicarol (Clark, *loc. cit.*).

A mixture of dehydrodihydrotoxicarol (1 g.), methyl sulphate (0·5 c.c.), acetone (40 c.c.), and potassium carbonate (3 g.) was heated on the steam-bath for 8 hours (a test sample of the product did not give a ferric reaction). On isolation, the *ether* (0·7 g.) separated from methyl alcohol–chloroform and then from alcohol–chloroform in almost colourless, squat prisms, m. p. 216°, having a negative ferric reaction [Found, in material dried in a high vacuum at 100°: C, 67·8; H, 5·7; OMe, 21·0. $C_{21}H_{15}O_4(OMe)_3$ requires C, 67·9; H, 5·7; OMe, 21·9%].

Methylation of dehydrodihydrotoxicarol (0·5 g.) with excess of silver oxide and of methyl iodide in boiling anisole (20 c.c.) during 5 days afforded the same methyl ether (0·3 g.), m. p. 216°, after purification from chloroform–methyl alcohol.

Dihydrotoxicarolic Acid Monomethyl Ether (II, R = Me).—The foregoing methyl ether (4·2 g.) dissolved in a warm mixture of alcohol (50 c.c.) and 30% aqueous potassium hydroxide (20 c.c.) in the course of 10 minutes, and after the addition of more 30% aqueous potassium hydroxide (20 c.c.) and zinc dust (0·5 g.) the solution was vigorously refluxed for 30 minutes, filtered, and acidified with excess dilute hydrochloric acid. Next day the precipitated *acid* (4 g.) was collected, well washed with water, and crystallised several times from dilute acetone (charcoal), forming clusters of colourless, elongated prisms, m. p. 203° after slight sintering at 198—200° (Found: C, 62·6; H, 6·3. $C_{24}H_{28}O_9$ requires C, 62·6; H, 6·1%). This compound, which readily dissolves in aqueous sodium bicarbonate with the liberation of carbon dioxide,

is moderately soluble in alcohol or acetone and gives a wine-red coloration with alcoholic ferric chloride.

Hydrolytic Fission of Dihydrotoxicarolic Acid Monomethyl Ether.—When a mixture of the acid (2·4 g.), alcohol (20 c.c.), and 50% aqueous potassium hydroxide (25 c.c.) was heated (oil-bath) in nitrogen to 200—205° during 20 minutes, the alcohol distilled, and at about 160—180° the dipotassium derivative of the acid, which appeared to be sparingly soluble in the concentrated aqueous potassium hydroxide, separated as a light brown layer. The mixture was then maintained at 205° for 15 minutes, cooled, and dissolved in water (150 c.c.), and the solution acidified with a slight excess of hydrochloric acid. After having been neutralised with sodium bicarbonate, the solution was thoroughly extracted with ether (6 × 50 c.c.), and the combined extracts washed, dried, and evaporated. The residual viscous brown residue was digested with three successive portions of boiling light petroleum (b. p. 40—60°) (40 c.c.), leaving a small amount of brown resin, and on being evaporated the combined light petroleum extracts gave a moderately viscous light brown oil, a specimen of which did not crystallise in the presence of a crystal of 7-hydroxy-5-methoxy-2 : 2-dimethylchroman. By means of excess of *p*-nitrobenzoyl chloride and warm pyridine, the main portion of the product was converted into the *p*-nitrobenzoate, which separated from 95% alcohol in characteristic yellow prisms, m. p. 123°, identical in every way with an authentic specimen (Found : C, 63·8; H, 5·1; N, 4·0%).

After the separation of the phenolic fraction, the aqueous liquors were acidified with excess hydrochloric acid and extracted with ether (8 × 50 c.c.). Evaporation of the washed and dried extracts left derric acid (0·7 g.), which separated from ethyl acetate–light petroleum (b. p. 60—80°) and then ether–ligroin in needles, m. p. 168°, undepressed by admixture with a synthetical specimen, m. p. 168° (Part II; J., 1932, 1380).

allo*Dihydrotoxicarolic Acid* (XVI, R = H).—When ether (200 c.c.) containing 5 : 7-dihydroxy-2 : 2-dimethylchroman (Part XII, *loc. cit.*) (5 g.), methyl 2-cyanomethyl-4 : 5-dimethoxyphenoxyacetate (Part IV, J., 1933, 1163) (5 g.), and well-powdered zinc chloride (6 g.) was slowly saturated with hydrogen chloride, the solid was gradually replaced by a viscous red oil. After 6 days more ether (50 c.c.) was added, the solvent decanted, and the oily residue triturated with fresh solvent (4 × 50 c.c.) to remove hydrogen chloride and hydrolysed with water (50 c.c.) on the steam-bath for 2 hours. Next day the semi-solid was collected and boiled with alcohol (60 c.c.) and 15% aqueous sodium hydroxide (40 c.c.), containing zinc dust (1 g.), for 1 hour, and the filtered solution acidified with excess dilute hydrochloric acid. The *acid* (3 g.) thus precipitated was purified by means of aqueous sodium bicarbonate and then by crystallisation from aqueous methyl alcohol (charcoal), forming a *hydrate* in transparent rectangular prisms, m. p. 148°, which gave a purple coloration with alcoholic ferric chloride (Found: C, 59·4; H, 6·3. $C_{23}H_{26}O_9,H_2O$ requires C, 59·5; H, 6·0%. Found, in material dried at 100° in a high vacuum : C, 61·7; H, 5·8. $C_{23}H_{26}O_9$ requires C, 61·9; H, 5·8%). Mixed with dihydrotoxicarolic acid, this compound melted at about 136°.

A mixture of the acid (1 g.), sodium acetate (0·6 g.), and acetic anhydride (14 c.c.) was gently boiled for 15 minutes, and after cooling, the anhydride was decomposed with alcohol (10 c.c.) and water (50 c.c.). Next day the solid (0·6 g.) was collected, well washed, and crystallised from methyl alcohol (charcoal), giving the *monohydrate* of the *O*-diacetyl derivative of the acid in tiny, colourless, rectangular prisms, m. p. 211—212°, soluble in dilute aqueous sodium hydroxide and having a negative ferric reaction (Found, in material dried in a desiccator at room temperature : C, 58·9; H, 5·6. $C_{27}H_{30}O_{11},H_2O$ requires C, 59·1; H, 5·8%). On being dried at 100° in a high vacuum, this compound appeared to undergo slight decomposition [Found : C, 61·0; H, 5·7. Calc. for $C_{27}H_{30}O_{11}$: C, 61·1; H, 5·7%. Calc. for $C_{25}H_{24}O_8$ (*O*-diacetyl*allo*-dihydrotoxicarol) : C, 66·4; H, 5·3%].

The same diacetate, m. p. and mixed m. p. 211°, was obtained when the *allo*dihydrotoxicarolic acid (1·4 g.) was vigorously refluxed with acetic anhydride (20 c.c.) and sodium acetate (1 g.) for 35 minutes. Deacetylation of this acetate (0·2 g.) by means of boiling alcohol (8 c.c.) containing concentrated hydrochloric acid (2 c.c.) for 15 minutes, and subsequent addition of water (50 c.c.) to the cooled solution, afforded *allo*dihydrotoxicarolic acid, which separated from aqueous methyl alcohol as the hydrate, m. p. 147°, having the characteristic ferric reaction.

[With WILLIAM HILTON.] *Phenoxyacetic Acid-2-phloracetophenone* (XVIII).—The condensation of methyl 2-cyanomethylphenoxyacetate (Part III, J., 1933, 492) (3 g.) and phloroglucinol (5 g.) in ether (50 c.c.) was effected with zinc chloride (3 g.) and excess of hydrogen chloride in the course of 4 days. After the addition of more solvent (100 c.c.), the ethereal layer was decanted, and the viscous dark brown product washed with ether (4 × 25 c.c.) and heated with water (100 c.c.) on the steam-bath for 1½ hours. Next day, the *keto-acid* was isolated and, after

having been separated from a small amount of a gelatinous solid by means of aqueous sodium bicarbonate (50 c.c.), formed colourless elongated prisms, m. p. 184—185° after sintering at 180°, and containing solvent of crystallisation, from 60% alcohol (Found, in a specimen dried in a high vacuum at 100°: C, 60·4; H, 4·7. $C_{16}H_{14}O_7$ requires C, 60·3; H, 4·4%). With alcoholic ferric chloride this compound gave a wine-red coloration.

5 : 7-Dihydroxychromeno-(3′ : 4′ : 2 : 3)*-chromone* (XIX, R = H).—The foregoing acid (1 g.) was boiled with acetic anhydride (14 c.c.) and sodium acetate (0·6 g.) for 15 minutes, the excess anhydride was decomposed with alcohol (10 c.c.) and water (24 c.c.), and next day the light brown *diacetate* (XIX, R = Ac) was collected, washed, and crystallised from ethyl alcohol (charcoal), forming colourless needles (0·2 g.), m. p. 240—241° after slight sintering at about 217°, having a negative ferric reaction (Found: 65·5; H, 4·2. $C_{20}H_{14}O_7$ requires C, 65·6; H, 3·9%).

Deacetylation of this compound (0·3 g.), dissolved in boiling alcohol (10 c.c.), was effected with concentrated hydrochloric acid (2·5 c.c.) in 15 minutes, and the *chromenochromone* precipitated by the addition of saturated brine (50 c.c.). Purified from 60% alcohol, this compound formed colourless needles (0·1 g.), m. p. 256—257°, readily soluble in alcohol or acetone and giving an olive-green coloration with alcoholic ferric chloride (Found: C, 68·2; H, 3·8. $C_{16}H_{10}O_5$ requires C, 68·1; H, 3·6%).

Cyclisation of Dihydrotoxicarolic Acid.—A mixture of the acid (2·7 g.), sodium acetate (1·5 g.), and 95% acetic anhydride (15 c.c.) was vigorously refluxed for 15 minutes, the greater part of the anhydride was removed in a vacuum, and the residue was treated with water (100 c.c.). Two days later the solid was collected, washed, and ground with excess of aqueous sodium bicarbonate. The insoluble residue was well washed with water and dissolved in boiling methyl alcohol. On cooling, the solution quickly deposited the acetate of dehydrodihydrotoxicarol in pale yellow prisms, m. p. 240°, after recrystallisation from acetic acid. Acidification of the aqueous sodium bicarbonate extract gave a precipitate of acidic material, which had only a faint ferric reaction and on deacetylation with *N*-aqueous sodium hydroxide furnished dihydrotoxicarolic acid identical with an authentic specimen.

The dark brown methyl-alcoholic filtrate from the crude acetate was warmed to about 50°, mixed with half its volume of 2*N*-aqueous sodium hydroxide, kept at room temperature for ½ hour, and poured into excess water. To facilitate the isolation of the colloidal product thus precipitated, it was adsorbed on a little charcoal and then extracted from the air-dried charcoal by means of boiling acetic acid. On cooling, the extract deposited a small amount of material which after repeated crystallisation from alcohol–acetic acid formed clusters of tiny yellow prisms, m. p. 238—239° (decomp.), sparingly soluble in alcohol and giving a dark green coloration with alcoholic ferric chloride.

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319. *Constituents of the Bark of* Zanthoxylum americanum (*Mill*). *Part IV. The Constitution of Xanthyletin.*

By (MISS) JANET C. BELL, WALTER BRIDGE, and ALEXANDER ROBERTSON.

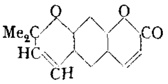
The present investigation, which is a continuation of that described in Part II (*J.*, 1936, 1828), was undertaken to obtain confirmatory evidence for the structures suggested for xanthoxyletin and its derivatives.

The orientation of cresorcylaldehyde and the ozonolysis and synthesis of dihydroxanthyletin are described. The results obtained, in conjunction with the analytical evidence described in Part II, serve to place the constitution of xanthyletin and its derivatives beyond doubt.

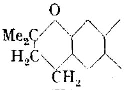
FROM the analytical evidence and the close similarity of the properties of xanthyletin and xanthoxyletin it was suggested in Part II (J., 1936, 1828) that the former compound is a chromeno-α-pyrone having the linear type of structure (I), and in the present memoir

conclusive analytical and synthetical evidence is described substantiating this expression in every detail. The evidence for this linear type of formula relies on the orientation of 7-hydroxy-6-methylcoumarin (Part II, *loc. cit.*) derived from the structure which Gattermann (*Annalen*, 1907, **357**, 340) proposed for cresorcylaldehyde but which had not been confirmed experimentally. The almost quantitative conversion of cresorcylaldehyde into *m*-xylorcin by Clemmensen's method of reduction, however, now serves to verify the orientation of this aldehyde and hence that of 7-hydroxy-6-methylcoumarin. On catalytic reduction, cresorcylaldehyde, unlike phloroglucinolaldehyde and its derivatives (J., 1936, 1837; this vol., p. 286), did not give satisfactory results and only small yields of *m*-xylorcin were obtained.

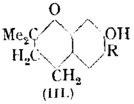
On ozonolysis, dihydroxanthyletin, which as indicated in Part II (*loc. cit.*) we believed to contain a double bond in the α-pyrone ring, gave rise to a product having the properties of an *o*-hydroxy-aldehyde, which, by analogy with the product obtained in a similar manner from dihydroxanthoxyletin (Part III, this vol., p. 286), was considered to be 7-*hydroxy*-6-*formyl*-2 : 2-*dimethylchroman* (III, R = CHO). The nature of this compound, in which the position of the formyl group clearly follows from the linear structure established for xanthyletin, was confirmed by its synthesis from 7-hydroxy-2 : 2-dimethylchroman (III, R = H), and consequently dihydroxanthyletin is represented by the expression (II). In this connexion it may be noted that, when submitted to the Gattermann reaction, the chroman (III, R = H) behaves in a manner strictly analogous to cresorcin (cf. remarks on 5 : 7-dihydroxy-2 : 2-dimethylchroman; Part III, *loc. cit.*).



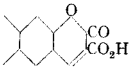
(I.)



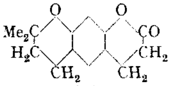
(II.)



(III.)



(IV.)



(V.)

The structure of dihydroxanthyletin (II) is confirmed by a complete synthesis of the compound from the synthetical aldehydo-chroman (III, R = CHO) : Interaction of the latter compound with cyanoacetic acid in aqueous sodium hydroxide and subsequent hydrolysis of the resulting salicylidenecyanoacetic acid gave rise to the *coumarin*-3-*carboxylic acid* (IV), which on decarboxylation furnished dihydroxanthyletin, identical in every way with a natural specimen. This result also serves to substantiate the formulæ proposed in Part II (*loc. cit.*) for *O*-methyldihydro- and for *O*-methyltetrahydro-xanthyletinic acid, and clearly shows that in xanthyletin the C_5 unit is present in a 6-atom-ring system. Catalytic hydrogenation of the disodium derivative of xanthyletinic acid, and subsequent lactonisation of the resulting tetrahydroxanthyletinic acid, gave rise to an almost quantitative yield of *tetrahydroxanthyletin*, thus confirming the presence of two double bonds in xanthyletin indicated by the formation of *O*-methyltetrahydroxanthyletinic acid. Of the ethylenic linkages, one is embodied in the C_5 residue and is preferentially attacked by hydrogen in the presence of a catalyst and by ozone, and the other, less reactive, is present in the α-pyrone ring, and consequently xanthyletin must be a chromeno-α-pyrone represented by the structure (I). Hence the tetrahydro-derivative has formula (V), and the structure suggested for *O*-methylxanthyletinic acid in Part II (*loc. cit.*) is substantiated.

EXPERIMENTAL.

Orientation of 2 : 4-*Dihydroxy*-5-*methylbenzaldehyde*.—The cresorcin, m. p. 104—105°, employed for the preparation of this aldehyde, which was used in the synthetical experiments described in Part II (*loc. cit.*), was prepared by the reduction of resorcylaldehyde according to

the method of Clemmensen (Ber., 1914, 47, 62), who, however, gives m. p. 83—84° for the phenol. The m. p. of the cresorcin obtained by us was identical with that given by Wallach (*Ber.*, 1882, 15, 2835) for material prepared by an independent method, and in view of this discrepancy the following experiments are described :—Pure resorcylaldehyde (10 g.), suspended in a little dilute hydrochloric acid, was added to a boiling mixture of 15% hydrochloric acid (120 c.c.) and alcohol (200 c.c.), containing amalgamated zinc dust (60 g.), during 1 hour, and after the addition of concentrated hydrochloric acid (15 c.c.) the mixture was refluxed for 2 hours. On isolation, the product had m. p. 88—89° after being once recrystallised from benzene, but on being purified by distillation in a vacuum, followed by repeated recrystallisation from benzene with or without sublimation in a vacuum, cresorcin, m. p. 104—105°, was finally obtained. This phenol having the same m. p. was also obtained when the reduction was effected with amalgamated zinc and 15% hydrochloric acid (8 hours), and it seems likely that the material described by Clemmensen as cresorcin was contaminated with small amounts of impurities encountered in these experiments and which are best removed by crystallisation from benzene.

Reduction of pure resorcylaldehyde (2 g.), dissolved in acetic acid (50 c.c.), with hydrogen (approx. 2 mols. absorbed) and a palladium–charcoal catalyst (from 5 g. of charcoal and 0·5 g. of palladium chloride) for 40 minutes gave an oily product from which a small amount of cresorcin, m. p. 106—107°, was obtained by crystallisation from benzene, followed by sublimation in a high vacuum. Mixed with material prepared by Clemmensen's procedure, it melted at 105—106°.

2 : 4-Dihydroxy-5-methylbenzaldehyde (5 g.), prepared from cresorcin, m. p. 104—105° (Gattermann, *Annalen*, 1907, 357, 340), was reduced with boiling 15% hydrochloric acid and amalgamated zinc dust (30 g.) in the course of 3 hours, giving rise to *m*-xylorcin, m. p. 116—118°, after distillation in a vacuum. On being twice recrystallised from benzene, this compound had m. p. 124° and was identical in every way with an authentic specimen (Robertson and Robinson, J., 1927, 2196). *m*-Xylorcin was also obtained in small yield by the reduction of 2 : 4-dihydroxy-5-methylbenzaldehyde, dissolved in acetic acid, with hydrogen and a palladium–charcoal catalyst, and had m. p. and mixed m. p. 123° after being purified by sublimation in a vacuum, followed by recrystallisation from benzene.

7-Hydroxy-6-formyl-2 : 2-dimethylchroman (III, R = CHO).—(A) Interaction of 7-hydroxy-2 : 2-dimethylchroman (Robertson and co-workers, this vol., p. 1532) (3 g.), dissolved in ether (110 c.c.), with hydrogen cyanide (7 c.c.) in the presence of excess of hydrogen chloride for 48 hours afforded a crystalline aldimine which, after the addition of more ether (80 c.c.), was collected, washed several times with ether, and hydrolysed with water (100 c.c.) on the steam-bath for 20 minutes. From the resulting product, which was isolated with ether, the *aldehyde* was extracted by means of excess of warm light petroleum (b. p. 40—60°) and purified by recrystallisation from the same solvent, followed by sublimation (twice) in a high vacuum, being finally obtained in colourless prisms, m. p. 104° (Found : C, 69·9; H, 6·8. $C_{12}H_{14}O_3$ requires C, 69·9; H, 6·8%). With alcoholic ferric chloride the substance gave a brown-red coloration. The 2 : 4-*dinitrophenylhydrazone* separated from ethyl acetate in orange-red, elongated, rectangular prisms, m. p. 302° (decomp.) (Found : N, 14·7. $C_{18}H_{18}O_6N_4$ requires N, 14·5%).

(B) A slow stream of ozone and oxygen was led into a solution of dihydroxanthyletin (*loc. cit.*) (1 g.) in dry chloroform (75 c.c.) for 1¾ hours, the solvent removed in a vacuum, and the residue hydrolysed with water (30 c.c.) at room temperature for 16 hours and then on the water-bath for 10—15 minutes. The resulting aldehyde was separated from a little unchanged dihydroxanthyletin with the aid of 1% aqueous sodium hydroxide, and crystallised from dilute alcohol or dilute acetic acid and then from light petroleum, forming colourless prisms, m. p. 103°, identical in every way with a synthetical specimen (Found : C, 69·8; H, 6·8%). The dinitrophenylhydrazone had m. p. 301—302° (decomp.) (Found : N, 14·3%).

Dihydroxanthyletin-3-carboxylic Acid (IV).—A solution of 7-hydroxy-6-formyl-2 : 2-dimethylchroman (1 g.) and cyanoacetic acid (4 c.c., of a solution prepared according to Phelps and Tillotson, *Amer. J. Sci.*, 1908, 26, 267) in 20% aqueous sodium hydroxide (10 c.c.) was kept at room temperature for 24 hours and acidified (Congo-red) with dilute hydrochloric acid. On being boiled with 4% hydrochloric acid (60 c.c.) for ½ hour, the yellow precipitate of the salicylidenecyanoacetic acid gave rise to the insoluble *coumarin-3-carboxylic acid*, which formed slender straw-coloured prisms, m. p. 158—159°, from 50% alcohol (Found : C, 65·7; H, 5·2. $C_{15}H_{14}O_5$ requires C, 65·7; H, 5·1%). An alcoholic solution of this compound exhibits a blue fluorescence.

Dihydroxanthyletin (II).—Decarboxylation of the foregoing acid (0·4 g.) was effected at 220° with the aid of copper-bronze in the course of 15 minutes, and the resulting dihydroxanthyletin

(0·25 g.) isolated from the reaction mixture by sublimation in a high vacuum at about 130°. Recrystallised from light petroleum (b. p. 60—80°), it formed colourless prisms, m. p. 125°, undepressed by admixture with a natural specimen (Found: C, 73·1; H, 6·2. Calc. for $C_{14}H_{14}O_3$: C, 73·0; H, 6·1%).

[With T. S. SUBRAMANIAM.] *Tetrahydroxanthyletin* (V).—20% Aqueous sodium hydroxide (2 c.c.) was added dropwise to xanthyletin (1 g.), dissolved in alcohol kept at 50°, the almost colourless solution was diluted with water (50 c.c.), and the disodium derivative of xanthyletinic acid was hydrogenated with an active palladium–charcoal catalyst (from 0·2 g. of palladium chloride and 1 g. of charcoal) and hydrogen at atmospheric pressure (approx. 200 c.c. absorbed; theoretical for $|\overline{_2}$, 205 c.c.) in the course of 1 hour. After the removal of the catalyst by filtration (wash with 20 c.c. of water), the solution was acidified (Congo-red) with 8% hydrochloric acid, and the colourless precipitate of tetrahydroxanthyletinic acid, m. p. 160° (efferv.), was collected, washed, and dried. On being kept at 180° for ½ hour, this compound was converted by loss of water into *tetrahydroxanthyletin*, which on being sublimed in a high vacuum was obtained in colourless rhombic prisms. Recrystallised from alcohol, it formed clusters of prisms, m. p. 156°, mixed m. p. with dihydroxanthyletin 115—117° (Found: C, 72·4; H, 6·9. $C_{14}H_{16}O_3$ requires C, 72·4; H, 6·9%).

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320. *Constituents of the Bark of* Zanthoxylum americanum *(Mill). Part V. The Structure of* allo*Xanthoxyletin.*

By ALEXANDER ROBERTSON and T. S. SUBRAMANIAM.

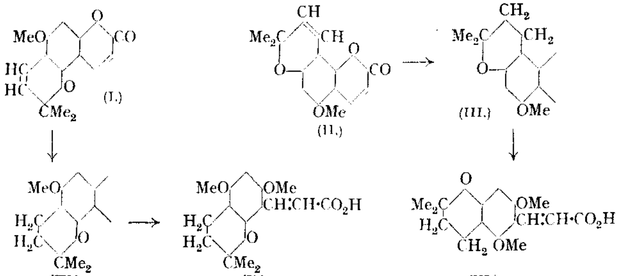
The structure of the new constituent *allo*xanthoxyletin, $C_{15}H_{14}O_4$, has been determined by application of the methods employed in the case of xanthoxyletin, with which it is isomeric. The behaviour of the compound on hydrolytic fission indicates that it is a 2 : 2-dimethyl-Δ^3-chromeno-α-pyrone derived from phloroglucinol monomethyl ether, and this view is supported by ozonolysis and hydrogenation experiments. In confirmation of the structures deduced for *allo*xanthoxyletin and its derivatives, a complete synthesis of dihydro*allo*xanthoxyletin from 7-hydroxy-5-methoxy-2 : 2-dimethylchroman is described.

Remarks on the absolute orientation of the monomethyl ethers of 5 : 7-dihydroxy-2 : 2-dimethylchroman and on the supposed occurrence of a furanocoumarin in the bark are included.

THE dark green oil, obtained in considerable quantities in the course of the isolation of xanthoxyletin (Part I, J., 1936, 627) by digesting the crude ethereal extract of the bark with light petroleum, did not yield solid material on being kept or on treatment with solvents, but on distillation in a high vacuum gave a fraction from which a small amount of a new compound, m. p. 115·5°, has been isolated. Occurring only in small quantities in the bark, this product, $C_{15}H_{14}O_4$, which is isomeric with xanthoxyletin and has been named allo*xanthoxyletin*, was separated in the first instance manually from mixtures of comparatively large crystals, and subsequently by a somewhat lengthy fractional crystallisation of the solid obtained on treating the distillate with a little light petroleum. It is a neutral substance devoid of hydroxyl or active carbonyl groups, contains one methoxyl group, and closely resembles xanthoxyletin in chemical properties. The behaviour of the compound with alcoholic sodium hydroxide is identical with that of the latter substance, indicating the presence of an α-pyrone system, and on hydrolytic fission with hot concentrated aqueous potassium hydroxide it gave rise to acetone and phloroglucinol monomethyl ether which, although obtained in insufficient quantity for purification by the usual methods, was recognised by the formation of the di-*p*-nitrobenzoate (compare Part I, *loc. cit.*). By analogy with xanthyletin (Part IV, preceding paper) and xanthoxyletin (Part III, this vol., p. 286), this result clearly indicates that *allo*xanthoxyletin is a 2 : 2-dimethyl-Δ^3-chromen derived from phloroglucinol monomethyl ether. With bromine water and dilute aqueous potassium permanganate *allo*xanthoxyletin behaves as a highly unsaturated

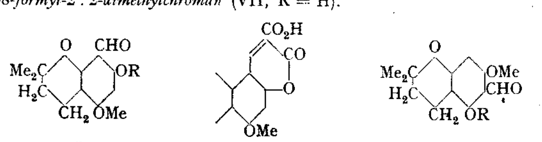
substance, and on hydrogenation with the aid of a palladium–charcoal catalyst gave rise to a *dihydro*-derivative. By the standard procedure this substance was converted into O-*methyldihydro*allo*xanthoxyletinic acid*, which was readily hydrogenated, yielding O-*methyltetrahydro*allo*xanthoxyletinic acid*.

On the basis of the foregoing analytical results, it appeared reasonably certain that *allo*xanthoxyletin is a 2 : 2-dimethyl-Δ^3-chromeno-α-pyrone which, in view of the established structure of xanthoxyletin (Part III, *loc. cit.*), must be represented by either of the angular formulæ, (I) or (II).



(I.) (II.) (III.) (IV.) (V.) (VI.)

Further, since in xanthoxyletin the double bond in the chromen system is preferentially attacked by hydrogen in the presence of a catalyst, therefore by analogy dihydro*allo*xanthoxyletin has either formula (III) or (IV), of which (III) is excluded because a compound having this structure would on simultaneous hydrolysis and methylation give rise to *O*-methyldihydroxanthoxyletinic acid (VI) (Part I, *loc. cit.*), whereas *O*-methyldihydro*allo*xanthoxyletinic acid is isomeric with and not identical with (VI). Consequently, *O*-methyldihydro*allo*xanthoxyletinic acid must have formula (V), and hence *allo*xanthoxyletin and its dihydro-derivative are represented by the expressions (I) and (IV) respectively. In support of these conclusions it has been found that ozonolysis of dihydro*allo*xanthoxyletin gave rise to an *o*-hydroxyaldehyde which, since it was identical with a synthetical specimen obtained by the application of the Gattermann reaction to 7-hydroxy-5-methoxy-2 : 2-dimethylchroman, and since both natural and synthetical products gave rise to 5 : 7-dimethoxy-8-formyl-2 : 2-dimethylchroman (VII, R = Me), must be 7-*hydroxy*-5-*methoxy*-8-*formyl*-2 : 2-*dimethylchroman* (VII, R = H).



(VII.) (VIII.) (IX.)

The foregoing structures proposed for *allo*xanthoxyletin and its derivatives have been conclusively confirmed by the complete synthesis of dihydro*allo*xanthoxyletin. Interaction of the synthetical aldehyde (VII, R = H) with cyanoacetic acid in aqueous sodium hydroxide, and subsequent hydrolysis of the resulting salicylidenecyanoacetic acid, furnished the *coumarin-3-carboxylic acid* (VIII), which on decarboxylation gave rise to dihydro*allo*xanthoxyletin, identical in every way with the natural product.

It may be noted that the conversion of 7-hydroxy-5-methoxy-2 : 2-dimethylchroman into the 8-formyl derivative (VII, R = H) clearly serves to confirm the orientation of

the former compound and to distinguish it from the isomeric 5-hydroxy-7-methoxy-2 : 2-dimethylchroman (George and Robertson, this vol., p. 1539). The latter substance could give rise to two aldehydes by Gattermann's method, *viz.*, 5-hydroxy-7-methoxy-6-formyl- (IX, R = H) and -8-formyl-2 : 2-dimethylchroman, of which the former would yield (IX, R = Me) (Part III, this vol., p. 286) on methylation, whereas the latter, although it would furnish (VII, R = Me), could not be converted directly into a coumarin.

EXPERIMENTAL.

allo*Xanthoxyletin*.—(A) Evaporation of the solvent from the light petroleum liquors obtained in the course of the isolation of xanthoxyletin (Part I, *loc. cit.*) left a viscous dark green oil which on distillation in a high vacuum gave an almost colourless fraction, b. p. 180—210°/0·04 mm. This material (50 g., from 200 g. of crude oil), which solidified at approximately 0°, was mixed with light petroleum (b. p. 60—80°) and on slow evaporation of the solvent the solution gradually deposited a crystalline product (2 g.) during 7 days. On isolation, the solid was washed with light petroleum (b. p. 40—60°) (20 c.c.) and then dissolved in boiling light petroleum (b. p. 60—80°) (30 c.c.), the solution was cleared (charcoal), one hour later the liquor was decanted, and the residual crystals were washed with fresh solvent (3—4 c.c.). On being kept at room temperature, the combined light petroleum liquor and washings, which had been warmed and allowed to cool, gradually deposited allo*xanthoxyletin* in pale yellow, elongated, thick prisms (0·2 g.), which on repeated crystallisation from light petroleum (b. p. 60—80°) was obtained in colourless, elongated prisms, m. p. 115·5°, easily soluble in benzene or ether and sparingly soluble in cold alcohol [Found: C, 69·8; H, 5·4; OMe, 13·0; *M*, 270. $C_{14}H_{11}O_3(OMe)$ requires C, 69·8; H, 5·4; OMe, 12·0%; *M*, 258]. This compound, which appears to be slightly more soluble in organic solvents than xanthoxyletin or xanthyletin, does not give a ferric reaction, and is insoluble in aqueous sodium hydroxide. The orange solution of the substance in concentrated sulphuric acid changes to orange-red in about a minute, and on being warmed on the water-bath becomes bright red and then colourless (compare xanthoxyletin; Part I, *loc. cit.*).

(B) *allo*Xanthoxyletin can be isolated from the distillate by the following alternative procedure. A solution of the oil (100 g.) in absolute alcohol (200 c.c.) was mixed with 60% aqueous potassium hydroxide solution, heated on the steam-bath for 10 minutes, diluted with water (600 c.c.), and extracted three times with ether. The alkaline aqueous liquors were then cleared with charcoal, filtered, and saturated with carbon dioxide, and the colourless crystalline precipitate which separated during 5 days was collected, washed, and dried. Fractional crystallisation of this material from warm light petroleum (b. p. 60—80°) finally gave *allo*-xanthoxyletin, m. p. 115·5°, identical with that obtained by method (A).

(C) Evaporation of the combined liquors obtained by repeated crystallisation of the crude mixture of chromenocoumarins (20 g.) (Part I, *loc. cit.*), consisting mainly of xanthoxyletin and xanthyletin, from much light petroleum, (b. p. 80—100°) gave a product from which *allo*-xanthoxyletin (0·1 g.) was obtained by fractional crystallisation from light petroleum (b. p. 60—80°).

Hydrolytic Fission of allo*Xanthoxyletin*.—Well-powdered *allo*xanthoxyletin (0·5 g.) was boiled with 25% aqueous sodium hydroxide (50 c.c.) for 30 minutes (the solid dissolved in the course of about 5 minutes), and the pale brown solution, which had gradually become deep reddish-brown, was then distilled with the frequent addition of water so as to keep the volume of the alkaline liquor constant. Treatment of the distillate (100 c.c.) with an excess of 2 : 4-dinitrophenylhydrazine hydrochloride in hydrochloric acid gave an orange-yellow precipitate of acetone-2 : 4-dinitrophenylhydrazone (0·2 g.), which was purified by repeated crystallisation from dilute alcohol; m. p. 125° undepressed by admixture with an authentic specimen, m. p. 127° (Found: N, 23·2. Calc. for $C_9H_{10}O_4N_4$: N, 23·5%).

The cooled alkaline solution remaining in the distillation flask was acidified (Congo-red) with hydrochloric acid, saturated with ammonium sulphate, and repeatedly extracted with ether. Evaporation of the combined dried extracts left a dark brown viscous residue, from which by distillation in a high vacuum a small amount of a pale yellow distillate, m. p. about 65°, was obtained, giving a negative reaction with alcoholic ferric chloride and a pale blue coloration with the aqueous reagent, identical with the behaviour of phloroglucinol monomethyl ether. Interaction of this product with excess of *p*-nitrobenzoyl chloride in the presence of pyridine gave rise to the di-*p*-nitrobenzoate of phloroglucinol monomethyl ether, m. p. and mixed m. p. 199—200° (Found: C, 57·6; H, 3·3; N, 6·3. Calc. for $C_{21}H_{14}O_9N_2$: C, 57·5; H, 3·2; N, 6·4%).

*Dihydro*allo*xanthoxyletin* (IV).—Hydrogen (approx. 1 mol.) was rapidly absorbed at atmospheric pressure by *allo*xanthoxyletin (0·5 g.), dissolved in acetic acid (30 c.c.) containing a palladium–charcoal catalyst (from 0·5 g. of charcoal and 5 c.c. of 1% aqueous palladium chloride), and after the removal of the catalyst and the evaporation of the solvent in a vacuum, the *product* separated from light petroleum (b. p. 80—100°) in thick colourless prisms (0·4 g.), m. p. 155° after sintering at 153° (Found : C, 69·3; H, 6·2. $C_{15}H_{16}O_4$ requires C, 69·2; H, 6·2%). This substance is moderately soluble in alcohol or benzene and readily soluble in chloroform.

O-*Methyldihydro*allo*xanthoxyletinic Acid*.—The foregoing compound (1 g.) was hydrolysed, and the resulting cinnamic acid methylated with excess of methyl sulphate and 20% aqueous sodium hydroxide by the standard procedure used for the preparation of xanthoxyletinic acid (Part I, *loc. cit.*). A solution of the product in a mixture of alcohol (70 c.c.) and water (30 c.c.), containing sodium hydroxide (6 g.), was kept at 80° for 10 minutes, diluted with water (400 c.c.), and acidified with hydrochloric acid. The *acid*, which had separated in colourless needles, was purified by means of aqueous sodium bicarbonate and then by recrystallisation from benzene–light petroleum (b. p. 60—80°), forming slender needles (0·7 g.), m. p. 178° (decomp.), having a negative ferric reaction [Found : C, 65·9; H, 6·8; OMe, 22·0. $C_{14}H_{14}O_3(OMe)_2$ requires C, 65·8; H, 6·9; OMe, 21·2%].

In the course of the purification of this acid a trace of an acidic compound, m. p. 205°, was isolated which gave a red ferric reaction.

Hydrogenation of O-methyldihydro*iso*xanthoxyletinic acid (0·15 g.) in acetic acid (20 c.c.) with a palladium–charcoal catalyst afforded O-*methyltetrahydro*allo*xanthoxyletinic acid*, which separated from light petroleum (b. p. 60—80°) in short colourless prisms (0·1 g.), m. p. 108·5°, readily soluble in aqueous sodium bicarbonate, benzene or alcohol [Found : C, 65·2; H, 7·4; OMe, 20·7. $C_{14}H_{16}O_3(OMe)_2$ requires C, 65·3; H, 7·5; OMe, 21·1%].

7-Hydroxy-5-methoxy-8-formyl-2 : 2-dimethylchroman (VII, R = H).—(A) A stream of ozone and oxygen (rate, approx. 100 c.c./min.) was led into a solution of dihydro*allo*xanthoxyletin (1 g.) in dry chloroform (50 c.c.) maintained at 0° for 2 hours; the colourless solution gradually became pale yellow. After the removal of the solvent in a vacuum the residue was digested with water (20 c.c.) at room temperature for 12 hours and then on the water-bath for 10 minutes, and the oily product isolated with ether. A solution of this material in ether (30 c.c.) was extracted with 2% aqueous sodium hydroxide (6 × 5 c.c.) and, on being saturated with carbon dioxide, the combined alkaline extracts gradually deposited the *aldehydo-chroman* as a pale yellow precipitate, which was collected, washed, and recrystallised from 50% alcohol, forming colourless slender needles (0·25 g.), m. p. 90° [Found : C, 66·1; H, 6·9; OMe, 13·3. $C_{12}H_{13}O_3(OMe)$ requires C, 66·1; H, 6·8; OMe, 13·1%]. The pure material, which is sparingly soluble in dilute aqueous sodium hydroxide, gives a wine-red coloration with alcoholic ferric chloride, and reduces warm Fehling's solution and ammoniacal silver nitrate. It separates from hot light petroleum (b. p. 60—80°) in clusters of colourless prisms.

(B) A slow stream of hydrogen chloride was led into a solution of 7-hydroxy-5-methoxy-2 : 2-dimethylchroman (George and Robertson, *loc. cit.*) (0·8 g.) in absolute ether (20 c.c.), containing hydrogen cyanide (1·2 c.c.), for 3 hours and the mixture kept for 12 hours. After the addition of more ether (200 c.c.) the reaction mixture was kept for 2 hours to allow the fine precipitate to coagulate, the solvent decanted, and the aldimine hydrochloride collected, washed with ether, and hydrolysed with water (30 c.c.) on the steam-bath for 30 minutes. The pale yellow aldehydo-chroman was collected, washed, dried, and crystallised from light petroleum (b. p. 60—80°), forming thick colourless prisms (0·6 g.), m. p. 90°, identical in every way with the compound obtained from dihydro*allo*xanthoxyletin (Found : C, 66·2; H, 6·8; OMe, 12·8%). Attempts to prove the presence of an expected isomeric product, 7-hydroxy-5-methoxy-6-formyl-2 : 2-dimethylchroman, in the residues left on purification of this compound were unsuccessful, but it must be noted that the amounts of material available were too small to enable us to certify the complete absence of the isomeride.

5 : 7-Dimethoxy-8-formyl-2 : 2-dimethylchroman (VII, R = Me).—On being distilled in a high vacuum, the product formed by the application of the Gattermann reaction to 5 : 7-dimethoxy-2 : 2-dimethylchroman (1·0 g.) (Part III, *loc. cit.*) was obtained as a thick oil which gradually solidified and then separated from light petroleum (b. p. 60—80°) in clusters of colourless thick prisms (0·4 g.), m. p. 107° [Found : C, 67·3; H, 7·2; OMe, 25·0. $C_{12}H_{12}O_2(OMe)_2$ requires C, 67·2; H, 7·2; OMe, 24·8%].

Methylation of 7-hydroxy-5-methoxy-8-formyl-2 : 2-dimethylchroman (0·2 g.), obtained from dihydro*allo*xanthoxyletin, with methyl iodide (2 c.c.) and potassium carbonate (2 g.)

for 3 hours gave rise to 5 : 7-dimethoxy-8-formyl-2 : 2-dimethylchroman (0·15 g.), m. p. 107°, after purification, identical in every way with a synthetical specimen (Found : C, 67·2; H, 7·3; OMe, 24·7%). The semicarbazone separated from hot alcohol in slender needles, m. p. 217—218°, undepressed by admixture with an authentic specimen (Part III, *loc. cit.*).

*Dihydro*allo*xanthoxyletin-3-carboxylic Acid* (VIII).—A mixture of synthetical 7-hydroxy-5-methoxy-8-formyl-2 : 2-dimethylchroman (0·3 g., well powdered), 20% aqueous sodium hydroxide (7 c.c.), and cyanoacetic acid (6 c.c. of a solution prepared according to Phelps and Tillotson, *Amer. J. Sci.*, 1908, **26**, 267) was agitated for 24 hours. The filtered bright yellow solution was acidified (Congo-red) with hydrochloric acid, and the canary-yellow precipitate collected, washed with water, and boiled with 4% hydrochloric acid (50 c.c.) for ½ hour. The solid dissolved in 5 minutes and was gradually replaced by a pale yellow crystalline precipitate of the *acid* (VIII) (0·35 g.), which formed slender yellow needles (0·3 g.), m. p. 240° (decomp.), from warm 50% alcohol, sparingly soluble in benzene or light petroleum, and readily soluble in aqueous sodium bicarbonate (Found : C, 63·1; H, 5·4. $C_{16}H_{16}O_6$ requires C, 63·1; H, 5·3%).

This acid (0·2 g.) was boiled with quinoline (4 c.c.), containing Kahlbaum's "Naturkupfer" (0·5 g.), for 10 minutes, the reaction mixture treated with chloroform (200 c.c.), and the filtered solution repeatedly extracted with 8% hydrochloric acid to remove the quinoline, washed with water, dried, and evaporated. The residue was triturated with aqueous sodium bicarbonate to remove traces of acidic material, and on being sublimed in a high vacuum (110°/0·03 mm.) the resulting dihydro*allo*xanthoxyletin formed small thick prisms (0·1 g.). Purified from light petroleum, it had m. p. and mixed m. p. 155° after sintering at 152°, and was identical in every way with a natural specimen (Found : C, 69·3; H, 6·3%).

APPENDIX.

In their memoir on the constituents of *Zanthoxylum fraxineum* (Wild) [*Zanthoxylum americanum* (Mill)], Dieterle and Kruta (*Arch. Pharm.*, 1937, **275**, 475) mention the presence of a furanocoumarin, m. p. 99—100°, but, although our investigation of the constituents of this bark is not yet completed, we have been unable to detect the presence of a pure compound answering to this description. In view of the isolation of *allo*xanthoxyletin, it is conceivable that small amounts of the chromeno-α-pyrone (II), as well as of the analogous isomeride of xanthyletin, may be present, and in our search for compounds of this type we have examined in some detail the mixture, m. p. about 100—105°, which tends to separate in the course of the isolation of xanthoxyletin and xanthyletin (Part II, J., 1936, 1828). By a series of somewhat lengthy fractional crystallisations from alcohol and inoculating the liquors alternately with crystals of xanthoxyletin and of xanthyletin, we have been able to resolve this product into xanthyletin and xanthoxyletin in addition to traces of *allo*-xanthoxyletin (see present paper).

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321. *Stereochemistry of Plato-tetrammines.*

By H. D. K. DREW, F. S. H. HEAD, and H. J. TRESS.

It has been claimed that the plato-tetrammine, [Pt ib$_2$]Cl$_2$, is resolvable into optical enantiomorphs, which would imply a non-planar distribution of four valencies about the platinum atom. In a previous paper, however, we described the isolation of *cis*- and *trans*-forms of this tetrammine, implying a planar distribution of valencies. The present paper describes attempts to resolve these *cis*- and *trans*-forms through the bromocamphorsulphonates : there was no resolution in either case, which supports our former conclusion. On the other hand, attempts to resolve a new plato-tetrammine, [Pt ib mt]Cl$_2$, which should be resolvable on a planar or on a tetragonal bisphenoidal but not on a regular tetrahedral basis of valency distribution about platinum, all failed, although a number of resolving agents were tried.

REIHLEN and also Rosenheim and their collaborators (see, *e.g.*, *Annalen*, 1931, **489**, 42; 1935, **519**, 80; 1935, **520**, 256; *Z. anorg. Chem.*, 1933, **210**, 289) have claimed evidence for

the optical resolution of plato-tetrammines. In particular, so far as the present work is concerned, Reihlen and Hühn (first reference, above) claimed the resolution of [Pt ib_2]Cl_2* as α-bromo-*d*-camphor-π-sulphonate. Although we showed later (J., **1934**, 221) that this chloride existed in well-defined *cis*- and *trans*-planar forms, and that Reihlen and Hühn probably examined a mixture of both, yet it was recognised that a tetragonal bisphenoidal arrangement of the platinum valencies, which is a conceivable, but rather improbable, alternative to the planar arrangement adopted by us, would demand that both forms of [Pt ib_2]Cl_2 should be resolvable (since the chelate groups must necessarily span the skew and not the perpendicular edges of the bisphenoid, otherwise only one form could occur).

We have now attempted to resolve both forms of [Pt ib_2]Cl_2, but in each case the bromocamphorsulphonate appeared to be optically homogeneous. The two *salts* were well-crystallised substances, distinct from one another in appearance and in degree of hydration; both before and after fractionation, they gave rise, respectively, to the characteristic α- and β-forms of [Pt ib_2]$PtCl_4$ described by us (*loc. cit.*). The result confirms our former conclusion and throws some doubt on the claim of Reihlen and Hühn as regards this particular case. The not very great differences in the rotatory powers of the various fractions observed by the above authors may possibly have been due to the heterogeneity of the bromocamphorsulphonic acid used, since theoretically this acid could be a mixture of four stereoisomeric forms.

A plato-tetrammine of the form [Pt (a—b) (a—Cde—a)]X_2 should be resolvable if of planar or of bisphenoidal but not if of regular tetrahedral configuration. We prepared iso*butylenediamino-β-methyltrimethylenediaminoplatinous chloride*, [Pt ib mt]Cl_2, but failed to resolve it through the highly crystalline *α-bromocamphor-π-sulphonate* and *α-nitrocamphorate*; the *d*-tartrate, examined in less detail, also gave a negative result. At this stage in the work, Mills and Quibell (J., **1935**, 839) described the resolution of a somewhat similar plato-tetrammine, [Pt ib sn]Cl_2 (sn = *meso*-NH_2·CHPh·CHPh·NH_2) by using diacetyl-*d*-tartaric anhydride. We accordingly tried this reagent and also dibenzoyl-*d*-tartaric anhydride with our plato-tetrammine, but without success. It was intended to repeat the work on a larger scale, but, being unable to continue, we record the new substances prepared.

EXPERIMENTAL.

β-Methyltrimethylenediamine (mt) was prepared by condensing potassium phthalimide with β-methyltrimethylene dibromide (Faworsky and Sokownin, *Annalen*, 1907, **354**, 358) in nitrobenzene at 185° (2 hours), and hydrolysing the purified bisphthalimido-compound with fuming hydrochloric acid (see Mann, J., 1927, 2904). The hydrochloride of the diamine formed prismatic needles, m. p. 192°. *iso*Butylenediamine (ib) was prepared as previously described (Drew and Head, J., 1934, 49); its dibenzoyl derivative melted at 181—182° (cf. Mills and Quibell, *loc. cit.*).

β-*Methyltrimethylenediaminoplatinous chloride*, Pt mt Cl_2, separated when a concentrated solution of potassium chloroplatinite containing a slight excess of mt was left for some hours at 0°; it contained a small proportion of the pink plato-salt of the tetrammine, from which it was separated by means of tetramminoplatinous chloride or by treatment with silver nitrate and then hydrochloric acid. It formed yellow rectangular needles from boiling water (Found: C, 13·2; H, 3·3; Pt, 55·3. $C_4H_{12}N_2Cl_2Pt$ requires C, 13·6; H, 3·4; Pt, 55·1%).

iso*Butylenediamino-β-methyltrimethylenediaminoplatinous chloride*, [Pt ib mt]Cl_2, was prepared by shaking together at 40—50° the powdered plato-diammine, Pt mt Cl_2 or Pt ib Cl_2, and a slight excess of the aqueous diamine, ib *or* mt; a colourless solution of the tetrammine resulted. The tetrammine was a hygroscopic white powder (Found: Pt, 43·9, 44·2. $C_8H_{24}N_4Cl_2Pt$ requires Pt, 44·1%), giving a pale red *chloroplatinite*, [Pt ib mt]$PtCl_4$, which separated from dilute hydrochloric acid as hexagonal and octagonal plates (Found: Pt, 54·9. $C_8H_{24}N_4Cl_4Pt_2$ requires Pt, 55·1%).

Ammonium α-bromo-*d*-camphor-π-sulphonate was prepared as colourless anhydrous prisms, having $[\alpha]_D + 85°$; $[M]_D + 279°$ ($c = 3·985$, in water) (Reihlen and Hühn, *loc. cit.*, give $[\alpha]_D + 83°$; $[M]_D + 273°$).

*α-Bis*iso*butylenediaminoplatinous α-bromo-*d*-camphor-π-sulphonate.* A solution of 0·65 g. of α-[Pt ib_2]Cl_2,$2H_2O$ and 0·89 g. of ammonium bromocamphorsulphonate in 12 c.c. of warm

* ib = NH_2·CMe_2·CH_2·NH_2; mt = NH_2·CH_2·CHMe·CH_2·NH_2.

water gave 0·62 g. of the *salt*; recrystallisation from 7 c.c. of hot water gave 0·32 g. (Found : Pt, 19·8. $C_{28}H_{50}O_8N_4Br_2S_2Pt$ requires Pt, 19·7%). From the original mother-liquor a further crop of the salt was obtained, and this, after crystallisation from water, weighed 0·38 g. All crops consisted of colourless, anhydrous, slender needles, sometimes with domed ends; they gave the same buff α-plato-salt with potassium chloroplatinite, and had practically the same rotatory power : $[\alpha]_D^{20°}$ + 56°; $[\alpha]_{5780}^{20°}$ + 58°; $[\alpha]_{5461}^{20°}$ + 69° (*c* = 2·5, in water).

β-*Bis*iso*butylenediaminoplatinous* α-*bromo*-d-*camphor*-π-*sulphonate* was obtained similarly, as flat colourless hexagonal needles, which, however, consisted of a *monohydrate* (Found : Pt, 19·6; H_2O, 1·7. $C_{28}H_{52}O_9N_4Br_2S_2Pt$ requires Pt, 19·4; H_2O, 1·8%); it was homogeneous to crystallisation, the rotatory power being $[\alpha]_{5780}^{20°}$ + 55°, $[\alpha]_{5461}^{20°}$ + 68° (*c* = 1·371, in water); all crops gave with potassium chloroplatinite the pink β-plato-salt.

iso*Butylenediamino*-β-*methyltrimethylenediaminoplatinous* α-*bromo*-d-*camphor*-π-*sulphonate* was prepared by mixing warm concentrated solutions of [Pt ib mt]Cl_2 and ammonium bromocamphorsulphonate. It formed colourless tetrahedral crystals from water, and slender rectangular needles from aqueous alcohol (Found : Pt, 20·1. $C_{28}H_{50}O_8N_4Br_2S_2Pt$ requires Pt, 19·7%). Optical separation failed from water or alcohol, or by preparing the salt in presence of excess of [Pt ib mt]Cl_2; the specific rotation of all crops in water was sensibly the same : $[\alpha]_D$ + 55° (*c* = 2·59); $[\alpha]_{5780}$ + 56° (*c* = 1·95); $[\alpha]_{5461}$ + 68° (*c* = 1·6). From a number of the fractions, [Pt ib mt]Cl_2 was recovered through formation of the chloroplatinite and double decomposition with the equivalent of tetramminoplatinous chloride, Magnus's salt being filtered off; the filtrates were in all cases inactive.

Sodium α-nitro-*d*-camphorate (Lowry and Steele, J., 1915, **107**, 1040) was obtained, by mixing alcoholic solutions of nitrocamphor and sodium hydroxide, as slender needles having $[\alpha]_D$ + 295°; $[\alpha]_{5780}$ + 308°; $[\alpha]_{5461}$ + 368° (*c* = 1·08, in water).

iso*Butylenediamino*-β-*methyltrimethylenediaminoplatinous* α-*nitro*-d-*camphorate* was prepared in aqueous medium; it crystallised from aqueous alcohol as the *monohydrate* (Found : C, 43·5; H, 7·1; Pt, 25·7; H_2O, 2·8, 2·4. $C_{28}H_{54}O_7N_6Pt$ requires C, 43·0; H, 7·0; Pt, 25·0; H_2O, 2·3%), decomposing when rapidly heated to 295°; it formed rosettes of white needles from water, and had $[\alpha]_D$ + 165°; $[\alpha]_{5780}$ + 173°; $[\alpha]_{5461}$ + 206° (*c* = 1·644, in water). There was no decisive change of the rotatory power on recrystallisation from water or on preparing the salt in presence of 0·5 equiv. of the nitrocamphorate. In all cases inactive material was obtained on converting the nitrocamphorate into the chloride.

Tartrates.—The *d*-tartrate, diacetyl-*d*-tartrate, and dibenzoyl-*d*-tartrate corresponding with [Pt ib mt]Cl_2 were prepared and fractionated, but were not analysed, since all fractions examined gave rise to inactive chloride.

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322. *Improved Preparations of Aliphatic Diazo-Compounds, and Certain of Their Properties.*

By Donald W. Adamson and J. Kenner.

The several factors determining the most advantageous mode of preparation of individual diazo-compounds are considered, and suitable conditions (which vary from case to case) are elaborated for relatively large-scale operations.

Free diazo-ethane, -propane, -*n*- and -*iso*-butanes have been isolated, their boiling points determined, and their absorption spectra in the visible and the near ultra-violet region examined.

It was mentioned in a previous paper (J., 1935, 286) that an ethereal solution of diazo-octane, obtained by our method, did not survive an attempt to concentrate it by fractional distillation. We have since isolated from similar solutions of diazo-methane and -ethane the *pyrazoline* derivatives (I) and (II), and also prepared them from mesityl oxide.

(I.) Me_2C——CH·COMe / CH_2—N=N Me_2C——CH·COMe / MeCH—N=N (II.)

The formulæ (I) and (II) are based on the rule established by v. Auwers (*Ber.*, **1933**, **66**, 1198), *viz.*, that diazo-methane and -ethane combine with αβ-unsaturated esters so that nitrogen becomes attached to the α-carbon atom; this rule, in turn, being an obvious consequence of the anionoid condition of the carbon atom of the diazomethane molecule. The products now in question exhibit the general characteristic of such pyrazolines that, although stable in presence of nitrogen, they are changed into brown oils on exposure to air. Apart from this we have, as detailed later, been able to obtain little positive evidence of their constitution. They show, however, a certain analogy with the product prepared by Kohler and Steele from diazoacetic ester and benzylideneacetophenone (*J. Amer. Chem. Soc.*, 1919, **41**, 1105), in a tendency to resinify in presence of acid.

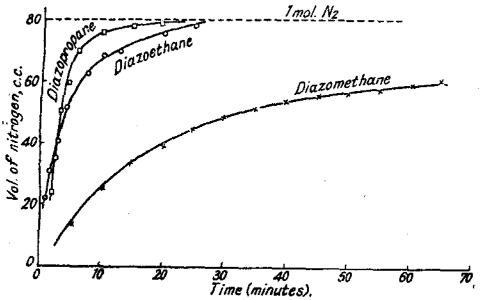
The formation of such products must be expected, not merely in the ethereal distillates, owing to volatilisation of some mesityl oxide, but also during the actual preparation of diazo-compounds by our procedure. This factor is additional to that discussed in the previous paper as contributing to a diminution in yield with increase in the scale of experiment, and may be to some extent counteracted by lowering the temperature employed from 80° to 50°. The following results show that very satisfactory results are thus achieved with moderately large quantities:

Nitroso-compound.	Yield of diazo-compound, g.	%
Methyl (⅓ mol.)	10·5	75
,, (½ mol.)	14·6	69·5
Ethyl (⅓ mol.)	12·9	69·2
n-Propyl (⅙ mol.)	7·5	65

In spite, therefore, of the difficulties indicated, the yields of diazomethane compare favourably with those claimed by Arndt ("Organic Syntheses," Vol. **15**, 3), and when

FIG. 1.

Reactivity of diazo-compound towards phenol.



account is taken of the instability of nitrosomethylurea and the stability of our nitroso-compounds, together with the improvement in their preparation described later (p. 1554), there can be little doubt that the new procedure is the best yet available for the preparation of ethereal solutions of diazomethane. A simple bulb fractionating column serves to obviate any considerable contamination with mesityl oxide, and the solutions may then be redistilled with very little loss.

The homologues are more reactive than diazomethane itself, as is evident from Fig. 1, in reference to the etherification of phenol. This fact, together with a diminution in volatility with rise in molecular weight, explains, in the light of the foregoing, the corresponding diminution in the yields of diazo-compounds prepared by the general method.

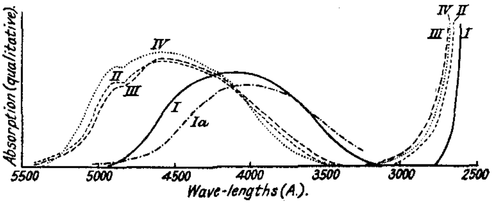
Nevertheless, the data already quoted show that very satisfactory preparations of diazo-ethane and -propane accrue from it.

A method more satisfactory for higher homologues, and in many circumstances also for those just discussed, resulted from the following considerations. Meerwein and Burneleit (*Ber.*, 1928, **61**, 1840), having shown that ether restrains the reactivity of diazomethane, prepared the gaseous compound in unspecified yield by the action of sodium glycollate on nitrosomethylurethane in a stream of nitrogen, and Arndt (*Z. angew. Chem.*, 1930, **43**, 444) obtained a 50% yield for the action of alcoholic potash on nitrosomethylurea. Excellent results (see *Nature*, 1935, **135**, 833) follow from gradual addition of our nitroso-compounds with anisole to a solution of sodium in benzyl alcohol or *cyclo*hexanol at 75—80° under reduced pressure. The appended results show the method to be also applicable to fairly large quantities.

Nitroso-compound.	Yield of diazo-compound, g.	%
Methyl (1/3 mol.)	8·8	63
Ethyl (1/5 mol.)	5·6	50
n-Propyl (1/6 mol.)	5·5	47
n-Butyl (1/6 mol.)	6·3	45

Highly concentrated solutions may be prepared by absorbing the diazo-ethane, -propane, or -butane thus obtained in any desired solvent or reactant at —50°, *e.g.*, 25 c.c. of ether for

Fig. 2.



I *Diazomethane.* I*a* *Diazomethane vapour* (*Kirkbride and Norrish*). II *Diazoethane.* III *Diazopropane.* IV *Diazobutane.*

the quantities mentioned in the table, but the volatility of diazomethane under reduced pressure is too great for this purpose unless an acid or other reactant is also present. In such circumstances, however, the process is more expeditious for the generation of diazomethane than the ether distillation method.

Small-scale experiments along these lines permitted the isolation of the free diazo-compounds and determination of their boiling points, *viz.*, diazoethane, — 19° to — 17°/89·5 mm.; diazo-*n*-propane, — 8° to — 7·5°/41·5 mm.; diazo-*n*-butane, — 3·5° to — 5·5°/26 mm.; diazo*iso*butane, — 1° to + 1°/32 mm.

The methane analogue has b. p. — 24° to — 23°/760 mm. (Staudinger and Kupper, *Ber.*, 1912, **45**, 507), and the *iso*propane compound b. p. — 31°/14 mm. (Staudinger and Gaule, *ibid.*, 1916, **49**, 1905). It may be emphasised that, neither in these nor in any other of our experiments, has there been any difficulty from the explosive character of the diazo-compounds.

By redistillation and collection of diazo-methane, -ethane, -*n*-propane, -*n*- and -*iso*-butane severally in *cyclo*hexane, solutions were prepared of which the absorption spectra in the visible and ultra-violet region down to 2100 A. were studied. As Fig. 2 shows, our results with diazomethane agree satisfactorily with those of Kirkbride and Norrish (J., 1933, 119), and in the homologues the main absorption band of diazomethane acquires a frequency lower by approximately 650 A., corresponding to the greater reactivity, and hence readiness of excitation, already mentioned. There is also a subsidiary band at 4900 A., which is not

shown by diazomethane. The colours of diazo-*iso*propane and -*sec.*-butane suggest that they might exhibit this band still more intensely.

The rise in boiling point renders the separation of mesityl oxide from gaseous homologues higher than diazobutane in the procedure described unsatisfactory, but this difficulty is overcome by using the less volatile pulegone. The well-crystallised *nitroso*-derivatives (III) prepared from this ketone afford the same yields of diazo-compounds as those previously employed, but are formed with less facility than those from mesityl oxide and hence are considerably more costly. For these reasons, our experiments in this direction have hitherto been confined to the small scale.

$$CMe_2{:}C{<}^{CH_2-CH_2}_{CO-CH_2}{>}CHMe \longrightarrow \underset{R\cdot N\cdot NO}{Me_2C}-CH{<}^{CH_2-CH_2}_{CO-CH_2}{>}CHMe \quad \text{(III.)}$$

EXPERIMENTAL.

Preparation of Nitroso-derivatives.—(a) *From mesityl oxide.* The following procedure is generally applicable, gives better yields than that previously described, and affords products which can be used without distillation for the preparation of diazo-compounds. An ice-cooled solution of methylamine hydrochloride (97%; 139 g.) in water (200 c.c.) was treated with a solution of sodium hydroxide (95%; 84 g.) in water (200 c.c.), and to the stirred mixture, maintained below 20°, mesityl oxide (196 g.) was gradually added during 1 hour. After a further hour, the mixture was slowly neutralised below 7° with glacial acetic acid (120 g.), and, without special cooling, treated successively with a solution of sodium nitrite (90%; 360 g.) in water (450 c.c.), and glacial acetic acid (180 g.). The mixture was stirred for 4 hours, and its temperature allowed to rise to, but not to exceed, 35°. The nitroso-compound was removed by two extractions with ether, followed by another after saturation of the aqueous liquor with salt. The combined extracts were washed twice with dilute acetic acid, once with calcium chloride solution (10%), and dried over calcium chloride. Finally, ether and impurities of low b. p. were removed at 100°/30 mm. Yield, 75—80%. The derivative from methylamine has now been obtained as a solid, m. p. 21—22°. (b) *From pulegone.* Ethylamine (9 g.), water (30 c.c.), and pulegone (30—40 g.) were stirred for 3 hours, and neutralised at 0° with hydrochloric acid (20%). By extraction with ether, pulegone (13·1 g.) was recovered, and the aqueous liquor was then treated with sodium nitrite (95%; 36 g.) in water (50 c.c.) and glacial acetic acid (18 g.). The mixture was occasionally cooled to keep its temperature below 35°, and stirred for 24 hours. The solid product was purified by crystallisation from light petroleum. The following table summarises the data in regard to the *nitroso*-derivatives (III) in question.

Alkyl group.	M. p.	N found, %.	N required, %.	Yield, %.
Me	116·5°	13·6	13·2	35
Et	108·5	12·7	12·4	41
n-Pr	125·5	11·9	11·7	36
n-Bu	89	11·3	11·0	38
n-C_5H_{11}	88·5	10·8	10·5	52
n-C_7H_{15}	70	9·8	9·4	38
Allyl	108	12·0	11·8	43

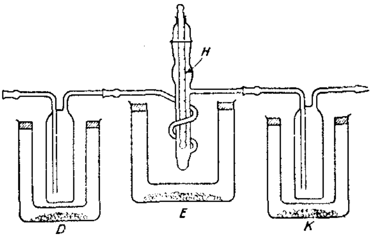
Preparation of Diazo-compounds. (a) *Ether distillation process.* The waxy mass prepared by dissolving sodium (2 g.) in *cyclo*hexanol (66 c.c.) was roughly broken up and added to dry ether (300 c.c.) in a 2-l. flask. After addition of nitroso-β-methylamino*iso*butyl methyl ketone (⅓ mol.) in dry ether (600 c.c.) at 10°, the mixture was slowly warmed by a bath at 50°. The vapour was passed through a bulb fractionating column to deposit mesityl oxide (this is unnecessary if the diazo-compound is to be employed for a rapid reaction, *e.g.*, esterification of an acid), and then through a condenser and an adapter into ether, until the condensate was colourless. Yield 10·3—10·8 g. in 730—750 c.c. of ether, and, from a similar experiment with ½ mol. of nitroso-compound, 14·6 g. in 1160 c.c. of ether. The yields of diazo-ethane and -propane from similar experiments have been already quoted. The use of benzyl alcohol in place of *cyclo*hexanol causes a slight reduction in yield, but a more rapid evolution, and hence about 30% greater concentration in the ethereal solution obtained. Final purification was, if desired, achieved by allowing the ethereal solutions to stand for one hour over solid caustic potash, and redistilling all but *ca.* 100 c.c. through a Widmer column. The loss thus occasioned is slight, except in the case of diazopropane.

(b) *Gaseous phase process.* A mixture of nitrosoethylamino*iso*butyl methyl ketone ($\frac{1}{8}$ mol.) with anisole (60 c.c.) was added during 15—20 minutes from a tap-funnel to the product from sodium (0·6 g.) and *cyclo*hexanol (20 c.c.) at 300—400 mm. pressure, in a 150 c.c. flask, heated by a bath at 75—80°, and fitted with an inlet tube for a stream of dry nitrogen, as well as a worm reflux condenser. The resulting diazoethane passed from the condenser successively through a cooling coil at 0° and a U-tube charged with solid potassium hydroxide into the selected solvent. Yield, 50%. Similarly for diazo-*n*-propane (yield, 47%), and at 30—50 mm. for diazo-*n*-butane (yield, 45%).

The process is also much more expeditious for diazomethane (yield, 65%), but in this case the gas must be absorbed in a reactant. Otherwise, a 2-l. flask containing dry ether (300 c.c.) was employed for the interaction of the nitrosomethylamino-ketone ($\frac{1}{8}$ mol.), delivered from a tap-funnel, with the product from sodium (1 g.) and *cyclo*hexanol (33 c.c.). The mixture was gradually warmed to 50°, and the diazomethane conveyed in a slow stream of nitrogen through an inverted Allihn condenser, and solid potassium hydroxide into ether (650 c.c.), cooled by a freezing mixture. Yield, after 35 minutes, 5·1 g. (72·9%) in 670 c.c. of ether. With $\frac{1}{3}$ molar quantities, 9·7 g. in 1250 c.c. of ether are obtained.

Isolation of Diazo-compounds, and their Boiling Points.—The gaseous diazo-compounds were prepared as just described in a 25 c.c. flask from the nitroso-ketone (0·3 mol.) in anisole (4 c.c.) and 3% sodium benzyloxide (3 c.c.) at 70° in an atmosphere of dry nitrogen at 50—100 mm. pressure. From the U-tube containing solid caustic potash, the gas passed to a receiver (*D*, Fig. 3) cooled by solid carbon dioxide and ether in a beaker, luted by asbestos-water glass into a larger one, containing also some calcium chloride. Obscurity by frost being thus prevented, the pressure was increased to atmospheric, and the receiver removed; 1—1·5 c.c. of liquid were seen to have been collected. The inlet being quickly stoppered, connection was made to the receiver *E*, cooled by solid carbon dioxide and ether. By reducing the pressure, and allowing the temperature of *D* to rise, distillation of the diazo-compound was accomplished. A small quantity of a colourless solid remained in *D*. It melted to a clear liquid with a characteristic odour, contained nitrogen, decolorised bromine or alkaline potassium permanganate, and was resinified by a trace of acid. Similar products were gradually produced from the diazo-compounds themselves at the ordinary temperature, but have not yet been further examined.

FIG. 3.



By causing the liquid diazo-compounds to distil from *E* to *K*, their b. p.'s (see p. 1553) were determined with the aid of the thermometer *H*.

Absorption Spectra.—Solutions in pure *cyclo*hexane of diazo-compounds, purified as already described, were analysed by titration with benzoic acid, and examined in the visible region by means of a Hilger–Nutting industrial spectrophotometer, and in the ultra-violet down to 2100 A. by a Bellingham and Stanley quartz spectrograph (No. 2.) in conjunction with a polarisation photometer. The molecular extinction coefficients, calculated from the Bunsen coefficients, varied slightly with the concentration of the solution, and small discrepancies appeared between results obtained by the two instruments in the same part of the visible region. The wave-lengths of the absorption bands were, however, identical under all conditions. The results are exhibited in Fig. 2, together with those of Kirkbride and Norrish.

Reactivity of Diazo-compounds towards Phenol.—A solution of pure diazo-methane, -ethane, or -propane in toluene (0·066 g.-mol./litre); 50 c.c.) was allowed to react at 0° in a flask, from which light was excluded, with a solution of pure phenol (0·0033 g.-mol.) in toluene (10 c.c.). The rate of evolution of nitrogen, measured at constant pressure, is shown in Fig. 1.

Reaction of Diazo-methane and -ethane with Mesityl Oxide.—(a) A solution of diazomethane (4·2 g.) in dry ether (600 c.c.) was evaporated in an atmosphere of nitrogen with a solution of mesityl oxide (9·8 g.) in dry ether (1000 c.c.) after the mixture had become colourless ($3\frac{1}{2}$ days). The residue, on distillation in nitrogen, yielded 6·2 g., b. p. 110°/18 mm., m. p. 50—53·5°. After crystallisation from light petroleum (b. p. 40°), the product melted at 51·5—52·5° (Found :

N, 19·9. $C_7H_{12}ON_2$ requires N, 20·0%). *5-Acetyl-4 : 4-dimethylpyrazoline* was also formed when a solution of nitrosomethylamino*iso*butyl methyl ketone (0·1 mol.) in alcohol (20 c.c.) was stirred with anhydrous potassium carbonate (4 g.) and dry ether (50 c.c.) below 20°. After 3 days, 0·044 mol. of nitrogen had been evolved, and the filtered liquor was distilled in an atmosphere of nitrogen. The main fraction (9·0 g.), b. p. 110—115°/18 mm., consisted of the pyrazoline. Although stable in nitrogen, it changed within 24 hours in a loosely stoppered bottle into a brown liquid, with a disagreeable odour. The pyrazoline was stable towards copper powder at 200°, and towards polished platinum at 230°; with semicarbazide in an atmosphere of nitrogen it yielded a product, m. p. 234—236° after four crystallisations from water, which was evidently not the desired semicarbazone (Found : N, 29·5, 29·7%), and was not further investigated. The presence of an acetyl group was indicated by an odour of bromoform observed when the pyrazoline was shaken with sodium hypobromite solution, but only a tarry product could be obtained on subsequent acidification with sulphurous acid.

(b) From diazoethane (5·6 g.) in ether (1000 c.c.) and mesityl oxide (9·8 g.) in ether (100 c.c.), *5-acetyl-3 : 4 : 4-trimethylpyrazoline* (Found : N, 18·3. $C_8H_{14}ON_2$ requires N, 18·2%), m. p. 76·3°, was similarly obtained. It was also prepared by decomposition of the nitrosoethylaminoketone by potassium carbonate, and was isolated in small amounts from ethereal solutions of diazoethane, prepared without precaution in respect of mesityl oxide. The pyrazoline, although stable in presence of nitrogen, rapidly liquefied in presence of air. When 3·1 g. were heated with 0·3 g. of copper powder at 185—200° in an atmosphere of nitrogen for 7 hours, they remained unchanged except for a few drops of distillate, from which a *semicarbazone*, m. p. 139—140° after crystallisation from benzene, was prepared. Its composition was that of the semicarbazone of 2 : 2 : 3-trimethyl*cyclo*propyl methyl ketone (Found : N, 23·1. $C_9H_{17}ON_3$ requires N, 23·0%).

We are pleased to express our thanks to Drs. O. R. Howell and H. Lowery for guidance in the measurements of absorption spectra.

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323. *The Stereochemistry of Quadricovalent Atoms: Cobalt and Manganese.*

By E. G. COX, A. J. SHORTER, W. WARDLAW, and W. J. R. WAY.

Stereochemical studies of the α- and the β-form of dipyridinocobaltous chloride have been made. Both these substances are monomolecular, and in the case of the α-chloride *X*-ray measurements show that the four groups linked covalently with the central cobalt atom have a *trans*-planar distribution, in striking contrast with the tetrahedral arrangement shown by Powell and Wells to occur in the $[CoCl_4]^{--}$ ion. Dipyridinomanganous chloride is found to be isomorphous with α-dipyridinocobaltous chloride; in this compound, therefore, the four covalencies of bivalent manganese also have a planar configuration.

β-Dipyridinocobaltous chloride is isomorphous with the only known forms of dipyridinocobaltous bromide and iodide; their stereochemistry is still uncertain.

FROM the stereochemical point of view, quadricovalent cobalt compounds present a problem of unusual interest. On the one hand, the ion $[CoCl_4]^{--}$ in Cs_3CoCl_5 has been shown by Powell and Wells (J., 1935, 359) to possess a tetrahedral configuration, and on the other hand the existence of two forms of diamminocobaltous chloride and similar substances, by analogy with the corresponding platinous compounds, has led to the suggestion (*e.g.*, by Biltz and Fetkenheuer, *Z. anorg. Chem.*, 1914, **89**, 97) that these substances are *cis*- and *trans*-isomerides of planar configuration. Sidgwick ("Electronic Theory of Valency," 1927, p. 230) has, however, pointed out that no certain conclusions as to the nature of the isomerism of the diammines of the cobaltous halides can be drawn from the available experimental evidence; nevertheless the possibility remained that bivalent cobalt might provide a definite example of a metal, in the same valency state, having both planar and tetrahedral quadricovalent derivatives.

In order to test this possibility we have made a new study, by chemical and crystallo-

graphic methods, of the two forms of dipyridinocobaltous chloride, $CoCl_2 2py$, and some related compounds. The violet α-form, which is stable at room temperature, was prepared in 1894 by Reitzenstein (*Annalen*, **282**, 267); the blue β-form was obtained by Hantzsch and Schlegel (*Z. anorg. Chem.*, 1927, **159**, 273), who dissolved the violet form in boiling chloroform and precipitated the β-chloride by addition of ligroin. This β-form is also obtained when the α-form is heated for a few hours in a sealed tube at 110—120°. Hantzsch and Schlegel prepared a blue bromide and a green iodide of analogous composition, which have so far been obtained in one form only. All these substances give red solutions in water, indicating decomposition. When the chloride $CoCl_2 2py$ is dissolved in acetone, alcohol or chloroform, a deep blue solution is obtained, and this, on evaporation at room temperature, deposits crystals of the α-form, independent of which form was originally dissolved. If, however, the evaporation takes place at a higher temperature, the β-form is produced. The same phenomena are observed when ligroin is added to a chloroform solution, *i.e.*, cold solutions yield the α- and hot solutions the β-form.

We have determined the molecular weights of the two forms by the cryoscopic method in phenol and by the ebullioscopic method in chloroform, obtaining results which indicate in both cases the simple formula $CoCl_2 2py$. The results in boiling chloroform fully establish the monomeric character of the β-form, which is the stable modification under the experimental conditions; since cobaltous chloride is insoluble in chloroform, any dissociation would readily be detected. The evidence of the molecular weights is not so valuable in the case of the α-form, on account of its possible transformation into the β-isomeride; our X-ray measurements on the crystalline α-modification, however, show clearly not only that it is monomeric, but also that it possesses a planar *trans*-configuration. This conclusion is based chiefly on the observation that the minimum distance between cobalt atoms in neighbouring molecules is 3·65 A.; so short a distance is only possible with molecules that are almost completely flat and therefore have their pyridine groups in *trans*-positions (cf. the case of the corresponding copper compound; Cox, Sharratt, Wardlaw, and Webster, J., 1936, 129). It has already been pointed out (Barkworth and Sugden, *Nature*, 1937, **139**, 374) that the assumption of the structure $[CoCl_4][Co4py]$ for the violet form leads to difficulties in the interpretation of the magnetism of cobalt complexes; this structure, and the other possible dimeric formula $[CoCl_3py][CoCl3py]$, are directly excluded by the X-ray data, since, as reference to models shows, neither the $[Co4py]^{++}$ nor the $[CoCl3py]^{+}$ ion could be sufficiently flat, on account of the mutual obstruction of the pyridine rings. Apart from this consideration, the short Co...Co distance with the dimeric formulæ would necessitate a most improbable structure in which ions of the same sign were in contact throughout the crystal.

The crystallographic evidence does not lead to any definite conclusion regarding the structure of the β-form, but it does show that it is isomorphous (and therefore, presumably, isostructural) with the only known forms of dipyridinocobaltous bromide and iodide. The interconversion of the α- and β-modifications with change of temperature and the fact that they are now both shown to be monomolecular suggest that they may be dimorphous forms of one compound having a planar *trans*-structure, but against this view are the pronounced differences in colour and magnetism; it remains a possibility that the β-form has a *cis*-planar or tetrahedral configuration.

The demonstration of the planar structure of α-dipyridinocobaltous chloride together with the previously established tetrahedral structure of the $[CoCl_4]^{--}$ ion (Powell and Wells, *loc. cit.*) appears to constitute the first definite case of a bivalent metal possessing simple unchelated quadricovalent derivatives of more than one configuration; this is in marked contrast with the stability of configuration among the metals of the platinum group, where considerable changes in the nature of the addenda and in the state of ionisation of the complex as a whole have no effect on the planar distribution of the four metal valencies. In the case of bivalent platinum in particular, the planar distribution of the bonds in many quadricovalent compounds has been demonstrated so completely both by chemical and by physical methods that there seems little room for doubt that no other configuration is possible. Whether the different behaviour of cobalt is to be attributed to possible altern-

ative electron distributions, to the nature of the links (co-ordinate or homopolar, etc.), or to other causes is a matter for further investigation.

We have also studied dipyridinomanganous chloride, $MnCl_2 2py$, and find that it possesses a planar *trans*-structure, being fully isomorphous with α-dipyridinocobaltous chloride. [It is of interest that the corresponding copper compound (Cox, Sharratt, Wardlaw, and Webster, *loc. cit.*), while remarkably similar in structure to the cobalt and manganese derivatives, is not isomorphous with them.] Apart from the phthalocyanin derivative (Linstead and Robertson, J., 1936, 1736) with its somewhat exceptional character, this appears to be the first demonstration of the configuration of a simple quadricovalent derivative of bivalent manganese. The result emphasises an aspect of the stereochemistry of the metals which we have previously pointed out, *viz.*, the dependence of configuration on principal valency, since, as is well known, both $[MnO_4]'$ and $[MnO_4]''$ are tetrahedral.

EXPERIMENTAL.

α-Dipyridinocobaltous Chloride.—Cobaltous chloride hexahydrate (26 g.) was triturated with pyridine (16 g.), and the mixture extracted with hot alcohol. On cooling, pale mauve crystals separated, which were recrystallised from alcohol, washed with alcohol and ether, and dried over phosphoric oxide in a vacuum (Found: Co, 20·7; Cl, 24·5; N, 10·1. Calc. for $CoCl_2,2C_5H_5N$: Co, 20·5; Cl, 24·6; N, 9·7%).

Cryoscopic determination in phenol (constant = 7·27° per 1000 g.). 30·32 G. per 1000 g. gave Δt = 0·863°, whence M = 255. 38·82 G. per 1000 g. gave Δt = 1·143°, whence M = 247.

Ebullioscopic determination in chloroform (constant = 26° per 100 ml.). 17·84 G. per 1000 ml. gave Δt = 0·136°, whence M = 341. 19·19 G. per 1000 ml. gave Δt = 0·141°, whence M = 354 (Calc. for $CoCl_2,2C_5H_5N$: M, 288).

β-Dipyridinocobaltous Chloride.—The α-form was heated in a sealed tube for a few hours. The tube was opened while still hot, and the contents transferred to a cool beaker in the absence of moisture. A blue powder was obtained (Found: Co, 20·7; Cl, 24·6%). A second method of preparation consists in dissolving the α-form in chloroform and adding ligroin to the boiling solution; a blue powder is at once precipitated; this is washed with ether and dried as above (Found: Co, 20·7%).

To obtain the β-form as *crystals*, a chloroform solution of the α-form is evaporated to dryness on the water-bath. The blue crystals are removed and dried as above (Found: Co, 20·3%).

Cryoscopic determination in phenol. 32·83 G. per 1000 g. gave Δt = 0·887°, whence M = 269. 59·33 G. per 1000 g. gave Δt = 1·521°, whence M = 284.

Ebullioscopic determination in chloroform. 13·31 G. per 1000 ml. gave Δt = 0·111°, whence M = 312. 12·85 G. per 1000 ml. gave Δt = 0·108°, whence M = 309.

β-Dipyridinocobaltous Bromide.—Hydrated cobalt bromide (20 g.) was dissolved in boiling alcohol, and pyridine (10 g.) added. Small blue crystals were obtained, recrystallisable from alcohol or chloroform (Found for a sample recrystallised from the latter solvent and dried over phosphoric oxide: Co, 15·7; Br, 42·3. Calc. for $CoBr_2,2C_5H_5N$: Co, 15·6; Br, 42·5%).

β-Dipyridinocobaltous Iodide.—Cobalt carbonate was dissolved in hydriodic acid, the solution evaporated to dryness, and the product recrystallised from alcohol. 20 G. of this cobaltous iodide were dissolved in boiling alcohol and treated with pyridine (10 g.). Small green crystals were obtained, which were washed with alcohol and ether and dried as before (Found: Co, 12·6; I, 53·9. Calc. for $CoI_2,2C_5H_5N$: Co, 12·5; I, 53·9%).

Dipyridinocobaltous Oxalate.—Hydrated cobalt chloride (2·4 g.) was dissolved in hot pyridine and added to a solution of oxalic acid (1·3 g.) in pyridine. A red powder was at once precipitated; this was filtered off, washed, and dried over calcium chloride (Found: Co, 19·2. $CoC_2O_4,2C_5H_5N$ requires Co, 19·3%).

It has also been found possible to obtain the β-form of dipyridinocobaltous chloride by a method described by Reitzenstein for the preparation of the compound $CoCl_2 2py,2C_2H_5{\cdot}OH$. If tetrapyridinocobaltous chloride is dissolved in alcohol, a blue compound crystallises. This substance, which rapidly reverts to a violet stable compound, was supposed by Reitzenstein to be the above alcoholate (no analyses were obtained), and the violet compound the α-form of dipyridinocobaltous chloride. We have confirmed the latter observation, but find that the blue substance (which we have isolated) is not the alcoholate, but β-dipyridinocobaltous chloride (Found: Co, 20·5%).

Crystallographic Results.—*X*-Ray measurements were made by means of single-crystal rotation and oscillation photographs with copper $K\alpha$ radiation.

α-Dipyridinocobaltous chloride occurs as thin needles, strongly dichroic, and showing nearly straight extinction. The crystals are monoclinic, the forms observed in the needle zone being $a\{100\}$ and $m\{110\}$ ($a : m = 62°$ approx.). The cell dimensions are $a = 17{\cdot}2$, $b = 34{\cdot}1$, and $c = 3{\cdot}65$ A.; $\beta \approx 90°$. The unit cell is c-face-centred and contains eight molecules of $CoCl_2 2py$ (d calc. = 1·81 g./c.c.; obs., 1·76). The space-group was not determined.

Apart from the small difference in the lengths of the axes, the c-axis rotation photograph of this substance is scarcely distinguishable from the corresponding one of dipyridinocuprous chloride ($b = 8{\cdot}4$, $a = 34{\cdot}0$, $c = 3{\cdot}84$ A.), so that from these photographs alone it might be inferred that the two are isomorphous; measurement of the other axes, however, shows that this is not the case, although there is clearly a very close relation between the two structures.

β-Dipyridinocobaltous chloride forms well-developed, six-sided, columnar crystals, originally deep blue, which break down to a pale blue powder after a few hours' exposure to the atmosphere. They appear to be orthorhombic combinations of a prism m with a pinacoid a ($a : m = 65°$ approx.), the length of the prism axis being $c = 8{\cdot}30$ A. This is a symmetry axis and appears to be the shortest cell dimension.

Dipyridinocobaltous bromide and iodide occur in imperfectly formed, six-sided, columnar crystals with $a : m = 65°$ and $63°$, and $c = 8{\cdot}42$ and $8{\cdot}68$ A. respectively. Comparison of the interfacial angles and the rotation photographs leaves no doubt that the bromide and iodide are isomorphous with the β-chloride, differing materially from the α-chloride. Owing to the deliquescence of these substances, more detailed examination could not be carried out.

Dipyridinomanganous chloride forms pale rose-pink, deliquescent needles, which, apart from colour, are similar in all respects to the crystals of α-dipyridinocobaltous chloride. The close correspondence of the X-ray photographs and of the angles in the c-zone ($a : m = 59°$ approx.) shows beyond doubt that the two substances are isomorphous. The length of the c-axis is 3·73 A.; on account of their deliquescence crystals could not be preserved long enough to measure the other axes accurately, but these are approximately the same as the corresponding axes in the cobalt compound ($a = 17$, $b = 34$ A.).

We are indebted to H.M. Department of Scientific and Industrial Research for a grant to one of us (A. J. S.).

The University, Birmingham, 15. [*Received, August 6th*, 1937.]

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324. *4-Phenyl*cyclo*hexylacetic Acid.*

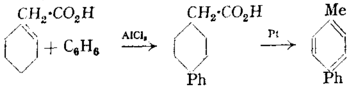
By J. W. Cook and F. Goulden.

The condensation between Δ^1-*cyclo*hexenylacetic acid and benzene in presence of aluminium chloride is attended by migration of a double bond (or its equivalent), for the only crystalline product isolated was 4-phenyl*cyclo*hexylacetic acid; the 2-phenyl*cyclo*hexylacetic acids which would be expected if migration did not occur were shown to be absent from the products.

One of us stated at a Meeting of the Society (Cook, *Chem. and Ind.*, 1937, **56**, 290) that condensation of Δ^1-*cyclo*hexenylacetic acid (I) with benzene in presence of aluminium chloride was accompanied by migration and gave, not 2-phenyl*cyclo*hexylacetic acid as claimed by Ghosh (*Science and Culture*, 1935, **1**, 299), but 4-phenyl*cyclo*hexylacetic acid (II). Ghosh (*ibid.*, 1937, **3**, 55) has recently remarked that " this does not seem plausible " and hence we wish to record the evidence on which the statement was based.

The two stereoisomeric 2-phenyl*cyclo*hexylacetic acids have m. p.'s 84—85° and 168—170° (Cook, Hewett, and Lawrence, J., 1936, 77). The acid obtained by Ghosh from benzene and *cyclo*hexenylacetic acid or hexahydro-α-coumaranone was stated to have m. p. 69—70°, but the mixed m. p. of the acids obtained from the two sources " was not observed as they did not have sharp melting points." If this acid were an impure specimen of the 2-phenyl*cyclo*hexylacetic acid of m. p. 85°, the reaction would furnish a convenient route to the hitherto almost inaccessible *trans*-hexahydrophenanthrone which it gives on dehydration (Cook, Hewett, and Lawrence, *loc. cit.*; compare Cook, *Chem. and Ind.*, 1937, **56**, 513). We have carried out condensations between Δ^1-*cyclo*hexenylacetic acid (I) and benzene in presence of aluminium chloride at 0°, at room temperature, and on the boiling water-

bath, and in all cases have obtained in moderately good yield a liquid mixture of acids from which crystals could be obtained by dilution with ligroin. After two recrystallisations this crystalline acid, of which the yield was only 7%, melted constantly at 113°, and was shown to be 4-*phenylcyclohexylacetic acid* (II) by dehydrogenation-decarboxylation with platinum-black to *p*-methyldiphenyl (III).



(I.) (II.) (III.)

The liquid mixture of acids which constituted the bulk of the reaction products we have not investigated, except to show that it was completely sulphonated by brief treatment with concentrated sulphuric acid at 100°, under which conditions the 2-phenyl*cyclo*hexylacetic acids are dehydrated to hexahydrophenanthrones. Therefore, 2-phenyl*cyclo*hexylacetic acids were not present in the reaction products. Pure 4-phenyl*cyclo*hexylacetic acid was likewise completely sulphonated by this treatment. Ghosh characterised his acid of m. p. 69—70° by conversion into its amide. This was stated to have m. p. 196—197°, in agreement with the value (195—196°) which we have found for the m. p. of the *amide* of 4-phenyl*cyclo*hexylacetic acid.

The formation of 4-phenyl*cyclo*hexylacetic acid in this reaction represents a type of migration which has not been much studied; it is, however, analogous to the production of 1 : 3- and 1 : 4-diphenyl*cyclo*hexanes, to the exclusion of the 1 : 2-compound, by condensation of benzene with 1 : 2-dibromo*cyclo*hexane in the presence of aluminium chloride (Nenitzescu and Curcăneanu, *Ber.*, 1937, **70**, 346).

EXPERIMENTAL.

Anhydrous aluminium chloride (10 g.) was gradually added to an ice-cold solution of Δ^1-*cyclo*hexenylacetic acid (10 g.) in pure dry benzene (50 c.c.). After ½ hour the mixture was kept at about 25° for 7 hours, the product decomposed with ice and hydrochloric acid, the benzene distilled in steam, and the residue extracted with ether. Acidic substances were removed from the extract by washing with dilute sodium carbonate solution, and were liberated by hydrochloric acid and re-extracted with ether. Distillation gave a colourless viscous oil (10 g.), b. p. 180°/0·8 mm., which yielded crystals, m. p. 106—108°, when diluted with ligroin (b. p. 80—100°). In another experiment a solution of the liquid distillate in light petroleum (b. p. 40—60°) was cooled in a freezing mixture; the m. p. of the crude crystalline material was then 80—106°. After two recrystallisations from ligroin 4-*phenyl*cyclo*hexylacetic acid* (II) formed colourless elongated plates, m. p. 112·5—113·5° (Found: C, 76·7; H, 8·4. $C_{14}H_{18}O_2$ requires C, 77·0; H, 8·3%). Yield, 0·5—1 g. Substantially the same result was obtained when the reaction mixture was kept at 0° for 18 hours or heated on the water-bath for an hour.

A solution in benzene of the chloride of 4-phenyl*cyclo*hexylacetic acid (0·5 g.), prepared by means of thionyl chloride, was treated with gaseous ammonia. The resulting *amide* crystallised from benzene in colourless leaflets, m. p. 195—196° (Found: C, 77·1; H, 9·0. $C_{14}H_{19}ON$ requires C, 77·4; H, 8·8%).

4-Phenyl*cyclo*hexylacetic acid (1·25 g.) was heated with platinum-black (0·25 g.) in an atmosphere of carbon dioxide at 305—310° for 4 hours. The product was extracted with ether and washed with dilute sodium carbonate solution. A little of the original acid was recovered from the alkaline extract. The neutral material was distilled at 0·2 mm. from a bath at 140—160°. The crystals which separated from the distillate were drained on a tile and recrystallised from alcohol; they then had m. p. 45—46°, not depressed by *p*-methyldiphenyl prepared by the method of Gomberg and Pernert (*J. Amer. Chem. Soc.*, 1926, **48**, 1375).

We are indebted to Dr. John Iball for completing the identification of the two specimens of *p*-methyldiphenyl by crystallographic comparison. He reports that under the polarising microscope both specimens gave identical interference fringes, and an *X*-ray examination by the powder method gave identical photographs with the two specimens.

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325. *The Composition of the Mixture of Rare Gases from the Hot Springs of Bath.*

By MORRIS W. TRAVERS.

The gases from the King's Well and the Cross Spring of Bath have been analysed. The rare-gas fraction consists in each case of argon with about 12% of helium and 0·1% of neon. The helium is certainly the product of radioactive change; the argon and neon are probably of atmospheric origin, the neon content being about half of that in the atmosphere on account of its lower solubility.

IN 1894 the late Lord Rayleigh determined the density of the rare-gas residue from the Bath Springs, and later examined the gas spectroscopically (*Phil. Trans.*, 1895, *A*, **186**, 227; *Proc. Roy. Soc.*, 1895, **59**, 207). Calculation based upon a determination of the density of the mixture of nitrogen and inactive gas, as obtained from the well, and an analysis of it, suggested that the helium–argon ratio might be as large as $\frac{1}{3}$, but a comparison of the spectrum of the gas with that of an artificial mixture of helium and argon indicated that the helium content of the Bath residue was somewhat greater than 10%. In 1912 Masson and Ramsay made a further examination of the gases from the Bath Springs, and attempted to separate the constituents by fractional absorption in charcoal cooled with liquid air, liquid hydrogen not being at that time available at University College, London. Their experiments led to the conclusion that the inactive residue contained a considerable quantity of neon, the residue from 1 l. of the gas, which originally contained no oxygen, and was freed from carbon dioxide, consisting of argon 7·33 c.c., neon 2·36 c.c., and helium 0·30 c.c. The presence of helium can of course be attributed to radioactive change, and the argon might be derived from the atmosphere. As to why the gas should contain so large a quantity of neon, since the solubility of that gas in water is less than that of argon, was a problem which remained unexplained.

Last year, I was asked by the Management of the Hot Springs to make a re-examination of the gases given off from the wells, and, knowing that the method employed by Masson and Ramsay was an unsatisfactory one, though it was the only method available, I agreed to do so, since, through the courtesy of Professor A. M. Tyndal and Dr. L. C. Jackson of the Department of Physics, University of Bristol, liquid hydrogen was available for the separation of the helium and neon from the argon. Mr. John Hatton, the Director of the Hot Springs, kindly made arrangements to enable me to collect samples of gas from the King's Well and from the Cross Spring.

It is not necessary to describe the method of operation in detail. The gases were collected in zinc gasholders, filled with water from the springs. In the case of the King's Well the gas from a chamber below the pool, which is filled with water, passed through a pipe to a small gasholder, in which it was collected. This pipe was disconnected from the gasholder, plugged with a rubber stopper, with a glass T-tube from which the sample was taken. In the case of the Cross Spring the gas was collected by placing a zinc funnel over a point in the floor of the pool from which bubbles of gas rose. In the first case the operation was complete in a few minutes; in the second it occupied several days. The gases were found to contain carbon dioxide and no trace of oxygen, showing that there was no contamination by air. In the first place 500 c.c. of each of the pure dry nitrogen–rare gas mixtures were analysed; they were found to contain:

King's Well, 12·8 c.c. of rare gas per l.
Cross Spring, 13·7 c.c. of rare gas per l.

Then, approximately 15 l. of the gas from each of the springs were passed over heated calcium, and yielded in each case about 335 c.c. of inactive gas. These samples of gas were used for the determination of the composition of the rare-gas residue. The gas samples were, in each case, then submitted to fractionation, liquid nitrogen being used as a cooling agent, seven approximately equal fractions being obtained. These were condensed in turn in a bulb cooled with liquid hydrogen, and separated into a volatile part containing helium and neon, and a non-volatile residue of argon. That the preliminary fractionation had been effective was shown by

the fact that of the first fraction about 75% was volatile, of the second about 5%, and of the third hardly a trace. The residues were refractionated, liquid oxygen being used as a cooling agent, and each fraction was again treated with liquid hydrogen, but only a trace of gas was obtained. Finally, the volatile fractions were mixed, and cooled with liquid hydrogen to freeze out any trace of argon contained in them.

The density of the lightest fraction showed that it consisted in each case of helium with no more than a trace of neon, indeed so little, that, using a 30 c.c. density bulb, it was only possible to determine the amount of it approximately. The non-volatile gas, after sparking with oxygen, was found to consist of pure argon. The following is the result of the analysis in c.c. per l. of the gas from the wells, dry and freed from carbon dioxide:

	King's Well.	Cross Spring.
Argon	11·12	12·22
Helium	1·66	1·47
Neon	0·01	0·01

The neon/argon ratio is then about one half of that found in the case of atmospheric air. As the argon and neon are probably dissolved in water when they find their way into the springs, this is to be expected.

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326. *Constitution of the Glucoside Butrin isolated from* Butea Frondosa *Flowers. Part I.*

By JAGRAJ B. LAL.

BUTRIN, the flavanone glucoside $C_{27}H_{32}O_{15},2H_2O$ isolated from the flowers of *Butea Frondosa* (Lal and Dutt, *J. Indian Chem. Soc.*, 1935, **12**, 4, 262), on hydrolysis with dilute mineral acids gives two molecules of glucose and one of butin, $C_{15}H_{12}O_5$, and is readily hydrolysed by emulsin, showing that it is a β-glucoside.

Butrin contains nine hydroxy-groups, but by the action of acetic anhydride and anhydrous sodium acetate at 130—135° it yields a *deca-acetyl* derivative, $C_{27}H_{22}O_5(O{\cdot}CO{\cdot}CH_3)_{10}$, owing to the rupture of the pyrone ring with simultaneous acetylation of the newly formed phenolic hydroxy-group of the chalkone. This behaviour is common among flavanone derivatives, *e.g.*, naringenin (Asahina and Inubuse, *Ber.*, 1928, **61**, 1514) and carthamidin (Kuroda, J., 1930, 753; *Proc. Imp. Acad. Tokyo*, 1929, **5**, 82). Butrin forms a *nonabenzoyl* derivative but a *tetra*-p-*nitrobenzoyl* derivative by usual procedures.

Methylation of glucosides of polyhydric phenols by methyl iodide and potassium carbonate in dry acetone has been shown to attack only the phenolic and not the hydroxy-groups (J., 1930, 2434), and King and Robertson (J., 1931, 1704) have shown that methylation of the flavanone glucoside hesperidin produces a syrup which yields on hydrolysis 4-hydroxy-2 : 6-dimethoxyphenyl 3 : 4-dimethoxystyryl ketone. Ethylation of butrin with excess of ethyl iodide and potassium carbonate in ethyl-alcoholic solution yields a white O-*diethylbutrin*, m. p. 238°, and an isomeric bright yellow product, m. p. 183·5°. The former is a flavanone derivative and contains no free phenolic group; since this is a diethoxy-compound, butrin must be regarded as a bioside of 7 : 3′ : 4′-trihydroxyflavanone, the position of the biose residue being still undetermined. The bright yellow compound is evidently a *chalkone*. Similarly, on methylation with methyl iodide and potassium carbonate, butrin yields a white O-*dimethylbutrin*, $C_{27}H_{30}O_{13}(OCH_3)_2,7\frac{1}{2}H_2O$, m. p. 224°. Hence, this method of ethylation or methylation, which opens up the pyrone ring completely in the case of hesperidin, does so only partly in the case of butrin, and consequently in butrin the flavanone configuration seems to be more stable than in hesperidin.

Butrin in alcoholic solution gives a pale yellow lead salt (Lal and Dutt, *loc. cit.*), but in hot aqueous solution it forms a bright yellow *lead* salt, $C_{27}H_{30}O_{13}(O{\cdot}Pb{\cdot}OAc)_2,2H_2O$, which must be derived from the chalkone corresponding to butrin, the transformation from flavanone to chalkone having been brought about during the course of its preparation.

Experimental.

4 G. of butrin, recrystallised from 200 c.c. of boiling water by slow cooling, formed a mass of white glistening needles; after standing overnight, these were collected, washed with water, and dried in air (38°) for several days (Found: C, 46·9, 47·1; H, 6·3, 6·3; loss at 120°, 13·6. $C_{27}H_{32}O_{15},5H_2O$ requires C, 47·3; H, 6·1; $5H_2O$, 13·1; $3H_2O$, 7·87%. Loss on keeping over H_2SO_4 or $CaCl_2$ for 10 days, 7·79, 7·64. Found, in dried sample: C, 51·2, 51·2; H, 5·7, 5·6. Calc. for $C_{27}H_{32}O_{15},2H_2O$: C, 51·3; H, 5·7%. Found, for anhydrous substance: *M*, cryoscopic in phenol, 560, 530. Calc. for $C_{27}H_{32}O_{15}$: *M*, 596).

The anhydrous substance, $[\alpha]_D^{30°}$ − 81·7° in pyridine (*c* 1·681), is very hygroscopic, taking up $2H_2O$ when exposed to air for a few hours. The dihydrate, which is also obtained by crystallisation from boiling rectified spirit (cf. Lal and Dutt, *loc. cit.*), is the most stable hydrate, $[\alpha]_D^{31·5°}$ − 73·27° in water (*c* 0·396).

Lead salt. To butrin (2 g.), dissolved in hot water (150 c.c.), a solution of lead acetate (2 g.) was added; no precipitation took place, although the solution turned yellow and then orange-yellow. On keeping overnight, an orange-yellow *lead* salt separated, which was filtered off and well washed with ice-cold water. Purification, by dissolving this in 50 c.c. of alcohol and adding water to turbidity, afforded ultimately a bright yellow granular precipitate, which was filtered off, washed, and dried in air (2 g.); m. p. 128° (shrinking at 115°). It is readily soluble in cold ethyl or methyl alcohol and in boiling water and is insoluble in other solvents [Found: C, 32·4; H, 3·4; Pb, 36·0. Loss at 80°, 2·7. $C_{27}H_{30}O_{13}(O{\cdot}Pb{\cdot}OAc)_2,2H_2O$ requires C, 33·0; H, 3·2; Pb, 36·9; $2H_2O$, 3·1%].

Nonabenzoyl derivative. To butrin (3 g.), dissolved in pyridine (50 g.), benzoyl chloride (45 g.) was gradually added with vigorous shaking during 5 hours. The product was recrystallised four times from boiling alcohol and obtained as colourless nodules which, after drying over anhydrous calcium chloride for a few days, had m. p. 141°; yield 5·4 g. (calc., 6 g.); $[\alpha]_D^{30°}$ of anhydrous sample + 77·28° in pyridine (*c* 2·525) [Found: C, 69·3, 69·5; H, 4·4, 4·4; loss at 95° for 18 hours, 1·2, 1·3. $C_{27}H_{23}O_6(O{\cdot}CO{\cdot}C_6H_5)_9,H_2O$ requires C, 69·7; H, 4·5; H_2O, 1·2%]. It gives with concentrated sulphuric acid an orange solution, but no coloration with magnesium and methyl-alcoholic hydrochloric acid.

Deca-acetyl derivative. A mixture of butrin (3 g.), anhydrous sodium acetate (3 g.), and acetic anhydride (20 g.) was heated at 130—135° for 5 hours, cooled, and diluted with a large volume of water; the resulting flocculent white precipitate (4·8 g.) crystallised from boiling methyl alcohol as very pale yellow flakes, which were dried over calcium chloride; m. p. 119—120° [Found: C, 54·4; H, 5·0; loss at 95°, 1·7, 1·7. $C_{27}H_{22}O_5(OAc)_{10},H_2O$ requires C, 54·6; H, 5·2; H_2O, 1·7. Found in anhydrous substance: C, 55·4; H, 5·2; $CH_3{\cdot}CO$, 43·4, 42·7. $C_{27}H_{22}O_5(OAc)_{10}$ requires C, 55·5; H, 5·1; $CH_3{\cdot}CO$, 42·3%]; $[\alpha]_D^{30°}$ for anhydrous substance − 79·86° in pyridine (*c* 1·224). It is very soluble in pyridine, glacial acetic acid, chloroform, carbon tetrachloride, ethyl acetate, and fairly so in ethyl and methyl alcohol and in acetone. Its colour reactions resembled those of the benzoyl derivative.

Carbethoxybutrin was prepared from butrin (3 g.), dissolved in pyridine (25 c.c.), and ethyl chloroformate (9 g.) in the usual manner, and was obtained on complete evaporation of solvent from methyl-alcoholic solution as a white amorphous mass, m. p. 83—84° after shrinking at 82° (4·3 g.). It is extremely soluble in all organic solvents.

Butrin oxime. This was prepared by refluxing a mixture of butrin (3 g.), hydroxylamine hydrochloride (3 g.), sodium acetate (4 g.), and ethyl alcohol (22 c.c.) for 8 hours. On concentration and subsequent addition of water, a white flocculent precipitate was formed, which, after five crystallisations from alcohol, was obtained as flakes (2·8 g.), m. p. 180° after shrinking at 165° (air-dried). It dissolves in sodium hydroxide to a colourless solution, which turns yellow on heating. With concentrated hydrochloric acid on heating it gives a deep yellow coloration, which with excess of alkali becomes orange (Found: C, 49·8; H, 5·55; N, 2·3; loss at 115°, 5·5; $C_{27}H_{33}O_{15}N,2H_2O$ requires C, 50·1; H, 5·7; N, 2·2; H_2O, 5·6%).

p-*Nitrobenzoyl derivative.* To butrin (2 g.), dissolved in pyridine (40 g.), powdered *p*-nitrobenzoyl chloride (22 g.) was added with vigorous shaking during 3 hours; the product was isolated, and crystallised from dilute pyridine in nodules, m. p. 154° (5·4 g.). It is extremely soluble in pyridine, readily soluble in acetone and ethyl acetate, fairly soluble in hot amyl alcohol, and insoluble in other solvents. It is insoluble in alkali hydroxide solutions [Found in air-dried substance: C, 54·0; H, 4·0; loss at 120°, 1·9. $C_{27}H_{28}O_{11}(C_7H_4O_4N)_4,H_2O$ requires C, 54·5; H, 3·8, loss H_2O, 1·5. Found in anhydrous substance: C, 55·3; H, 3·7; N, 4·8. $C_{27}H_{28}O_{11}(C_7H_4O_4N)_4$ requires C, 55·3; H, 3·7; N, 4·7%]; $[\alpha]_D^{30°}$ of anhydrous substance, − 44·30° in pyridine (*c* 2·891).

O-Methylbutrin. This was prepared from butrin (6 g.), dissolved in 5% potassium hydroxide (40 c.c.), by gradually adding methyl sulphate (80 g.) and potassium hydroxide (30%) below 40°; it was obtained as a deep yellow, brittle mass (6·4 g.), m. p. 82—84°, on complete evaporation of the usual organic solvents, but could not be obtained crystalline.

Ethylation of Butrin with Ethyl Iodide.—A suspension of butrin (4 g.) and finely powdered anhydrous sodium carbonate (10 g.) in a mixture of ethyl alcohol (200 c.c.) and ethyl iodide (9 g.) was heated under reflux on the water-bath for 13 hours; more ethyl iodide (13 g.) and sodium carbonate (8 g.) were added, and the mixture refluxed for another 13 hours. The boiling mixture was filtered, and the dry residue twice extracted with alcohol; it was then quite white, and on treatment with cold water left a white crystalline residue which was filtered off and washed free from sodium salts. *O-Diethylbutrin* was obtained as tiny white needles (1·9 g.), m. p. 238°, on recrystallisation from boiling water [Found in sample dried at 120°: C, 56·0, 56·1; H, 6·1, 6·1; OEt, 13·8, 14·1, 14·0. $C_{27}H_{30}O_{13}(OEt)_2,\frac{1}{2}H_2O$ requires C, 56·3; H, 6·2. $C_{27}H_{30}O_{13}(OEt)_2$ requires C, 57·05; H, 6·1; OEt, 13·8. Found, in air-dried sample: loss at 120°, 16·4. $C_{27}H_{30}O_{13}(OEt)_2,7\frac{1}{2}H_2O$ requires $7H_2O$, 16·0%]. On boiling with alcohol it becomes light yellow (m. p. 236°). It is insoluble in benzene, chloroform, ethyl acetate, acetone, ethyl and methyl alcohol. *O*-Diethylbutrin very slowly dissolves in alkali hydroxide but is insoluble in alkali carbonate solutions. On reduction with magnesium and methyl-alcoholic hydrochloric acid it gives a reddish-violet coloration.

The hot, yellow, alcoholic extracts on cooling after concentration deposited deep yellow crystalline nodules which melted completely at 166° although droplets appeared at 142° (yield 2·2 g.). These were boiled with alcohol and the small quantity of white substance, m. p. 232°, remaining undissolved was identified as *O*-diethylbutrin. The alcoholic filtrate on concentration deposited bright yellow crystals, m. p. 154—160°, raised by two crystallisations from slightly diluted alcohol to 183°. It is soluble in alkali hydroxides to a yellow solution, and slightly soluble in alkali carbonate. It is the *chalkone* derivative isomeric with white *O*-diethylbutrin [Found, in sample dried at 140°: C, 55·2, 55·4; H, 6·0, 6·1. $C_{27}H_{30}O_{13}(OEt)_2,H_2O$ requires C, 55·4; H, 6·3. Found, in air-dried sample: loss at 125°, 8·3. $C_{31}H_{40}O_{15},4\frac{1}{2}H_2O$ requires $3\frac{1}{2}H_2O$, 8·6%].

Methylation of Butrin with Methyl Iodide.—A suspension of butrin (4 g.) and anhydrous potassium carbonate (4 g.) in methyl alcohol (200 c.c.) and methyl iodide (13 g.) was heated under reflux on the steam-bath for 13 hours; more methyl iodide (5 g.) and potassium carbonate (4 g.) were then added and the mixture was refluxed for another 10 hours. The hot mixture was filtered, and the residue washed with methyl alcohol. The dry residue was freed from potassium salts by treatment with 70 c.c. of distilled water, and recrystallised from boiling water in tiny white needles, m. p. 224° (3·4 g.) (Found: C, 45·8, 45·9; H, 6·8, 6·8; loss at 140°, 17·9. $C_{29}H_{36}O_{15},7\frac{1}{2}H_2O$ requires C, 45·9; H, 6·7; loss, 17·8%. Found, in a sample dried at 140°: C, 54·9, 54·8; H, 5·9, 5·8; CH_3O, 9·9, 10·2. $C_{29}H_{36}O_{15},\frac{1}{2}H_2O$ requires C, 55·0; H, 5·8; CH_3O, 9·8%).

O-Dimethylbutrin is insoluble in benzene, chloroform, carbon tetrachloride, acetone, ether, and light petroleum, slightly soluble in boiling ethyl and methyl alcohol and in cold water but readily in boiling water, and extremely soluble in pyridine. It gradually dissolves in alkali hydroxides to bright yellow solutions, but is insoluble in alkali carbonate solutions. It gives a reddish-violet coloration with magnesium and methyl-alcoholic hydrochloric acid and is a flavanone derivative.

Action of Hydrogen Peroxide on Butrin.—To an ice-cooled mixture of butrin (2·2 g.) in methyl alcohol (100 c.c.), 4% hydrogen peroxide (80 c.c.) and 16% potassium hydroxide (20 c.c.) were added under ice cooling. When kept at 0—5° for 24 hours, the orange-red solution turned bright yellow, and bright yellow nodules separated. The solution on treatment with excess of carbon dioxide, concentration at ordinary temperature to 20 c.c., and extraction with acetone and methyl alcohol in succession gave no crystalline substance, but on hydrolysis with dilute mineral acid and concentration it deposited tiny pale yellow needles, giving a green coloration with neutral ferric chloride. On recrystallisation, these had m. p. 360° and were identified as fisetin (Found, in sample dried at 130°: C, 62·8; H, 3·8. Calc. for $C_{15}H_{10}O_6$: C, 62·9; H, 3·5%).

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327. *Dehydration Nuclei on Crystals of Copper Sulphate Pentahydrate.*

By W. E. GARNER and H. V. PIKE.

THE shapes of the dehydration nuclei formed on nine faces of crystals of copper sulphate pentahydrate have been studied, and it is shown that dehydration occurs most rapidly along definite crystal planes. The 010 plane is the most important of these, and possible causes of the rapid dehydration along this plane are discussed in the light of the *X*-ray structure of the salt as determined by Beevers and Lipson.

THE shape of the nuclei formed on the (110) face of crystals of copper sulphate pentahydrate has been investigated previously (J., 1934, 1874). On this face the nuclei are star-shaped in the plane of the surface and possess an extension inward in the form of a flat disc which makes an angle of 56° to the surface. The longer arms of the star, from which the disc is suspended, are parallel to the *c* axis of the crystal, and the shorter arm makes an angle of approximately 56° to this axis. The production of a star-shaped figure is a matter of some interest, for it shows that dehydration occurs preferentially along certain directions in the crystal. In order to determine more precisely the planes along which rapid dehydration occurs, the shapes of the nuclei formed on nine different faces of the copper sulphate crystal have been examined, and the directions of growth measured with respect to certain crystal edges. An attempt has been made to correlate these directions with the mode of arrangement of the water molecules in the crystal (cf. Beevers and Lipson, *Proc. Roy. Soc.*, 1934, *A*, **146**, 1570).

EXPERIMENTAL.

The apparatus was similar to that used in the earlier investigations. The crystals were prepared from a slightly supersaturated solution of Kahlbaum's copper sulphate in a dust-free atmosphere, the evaporation of the solution being brought about by the adsorption of water on solid sodium hydroxide placed at the bottom of the crystallisation chamber. The designation of the crystal faces is that due to Tutton ("Crystallography," 1911, p. 286). The *p*, *p'*, *a*, and *b* faces in the prism zone and the *o* and *t* faces were readily obtained of a suitable size for examination, but in order to obtain *t'*, *s'*, and *p''* faces of a sufficient size, it was necessary to grow large crystals. These large crystals were then broken down to a suitable size for suspension in the apparatus. The rare *c* face could not be obtained. The nuclei were formed and grown in a hard vacuum, and the crystal then removed from the apparatus and mounted on the stage of a microscope. The photographs shown in the plate were then obtained.

Nuclei.—The upper row of the plate gives the photographs of those nuclei formed on the prism zone, and they are placed in the order in which the faces occur on rotating the crystal about the *c* axis, commencing with the *p'* face. The second row gives the nuclei appearing on the various end forms.

The nuclei formed on the prism zone all showed the most prominent direction of growth parallel to the *c* axis. A second and sometimes a third direction of growth also occurred, and these made angles with the *c* axis which varied from face to face. When two subsidiary directions of growth occurred, these were sometimes found on the same nucleus (see *a* and *b* on the plate) or occurred on different nuclei as on the *a* face. As will be seen from the photograph of nuclei on the *p'* face, the subsidiary directions of growth are sometimes absent. Thus there is an element of chance in the starting of growth in the subsidiary directions. The subsidiary horns on either side of the main directions of growth do not always spring from the same point along the *c* axis, and this makes it difficult to measure the angles with any certainty. There are, however, ribs passing down the middle of the horns and the intersection of these ribs is usually clearly visible. The angles given below are average values of the angles between the intersecting ribs. These give at the most the general direction of the rapid growth, for in certain cases there are wide fluctuations in the angles.

A striking feature of many nuclei is the formation of a halo which is due to growth along a plane into the interior of the crystal. This halo always grows towards the *b* face of the crystal, and its intersection with the surface gives the most prominent direction of growth on the surface. The angle the halo makes with the surface was measured only for the *p* face, and here the found angle of 56° is in agreement with the angle between the *b* and *p* faces, *viz.*, 53° 4' (Tutton, *op. cit.*, p. 288).

The angles between the main and the subsidiary directions of growth of the nuclei on the faces in the prism zone are given below, the angles being reckoned in an anticlockwise direction :

Face	*p*′(1$\bar{1}$0)	*p*″(1$\bar{2}$0)	*b*(010)	*p*(110)	*a*(100)
Angle	31° 30′	33°	51°	56°	87°
			303°		28—52°

In the case of the *a* face there was an ill-defined direction of growth ranging between 28° and 52°. In all, twelve nuclei were measured on this face, and the angles varied uniformly between these limits. In the other cases, the variation in the angle was ± 3°, except for the *p* face, where the variation was smaller. The nuclei on the *b* face are exceptional in that they are lozenge-shaped and show no marked horns. The main direction is always parallel to the *c* axis.

The direction of the growth on the end faces was measured with respect to some crystal edge. The data are given below.

Face.	Zone.	Main direction of growth.	Subsidiary direction of growth.	Angle between directions of growth. Exptl.	Calc.
o,($\bar{1}$11)	[*pot*]	‖ to *bo* edge	‖ to *ao* edge	69°	67°
t,(021)	[*pot*]	‖ to *bt* edge	approx. ‖ to *p′t* edge	72°	—
t′(0$\bar{2}$1)	[*at′s′*]	‖ to *bs′* edge	‖ to *t′s′* edge *	69° 30′	70°
s′($\bar{1}\bar{2}$1)	[*at′s′*]	‖ to *bs′* edge	‖ to *t′s′* edge *	71°	68°

* Shown as white lines on Plate I.

The main direction of growth on all the end faces is parallel to the edge between the face in question and the *b* face, *i.e.*, it lies in the *b*(010) plane. This is in accord with the fact that the main direction on the prism zone also lies in the 010 plane. The subsidiary direction of growth in the case of the *o*, *t*′, and *s*′ faces is parallel to the edge between the face in question and the *a* face, *i.e.*, it lies in the *a*(100) plane. The subsidiary direction on the *t* face is exceptional in that it does not lie in the 100 plane. It probably lies in the 1$\bar{1}$0 plane.

It will be noted that the prominent directions of growth lie in definite crystal planes. The 010 plane is particularly important, for it is the plane along which the haloes penetrate the crystal. Also the main directions of growth of all the nuclei are parallel to the *c* axis and hence lie in the 010 plane. The nuclei on the end faces, *o*, *t*′, and *s*′, possess a subsidiary direction of growth lying in the 100 plane, but this is not so important as the 010 plane, since no halo is ever observed in it.

The subsidiary directions of growth on the faces of the prism zone, *p*′, *p*″, *b*, *p*, and *a*, and on the *t* face are difficult to interpret, but even here certain regularities emerge. These directions only in one case lie in the 001 plane, growth in this plane being inhibited for some reason. Apart from this one exception (see *a* face below), there is a component along the *c* axis in the direction of growth, so that the subsidiary directions of growth take diagonal paths across the unit cell. The data are given below, the crystal directions being expressed in the usual nomenclature, and the experimental and the calculated angles are compared.

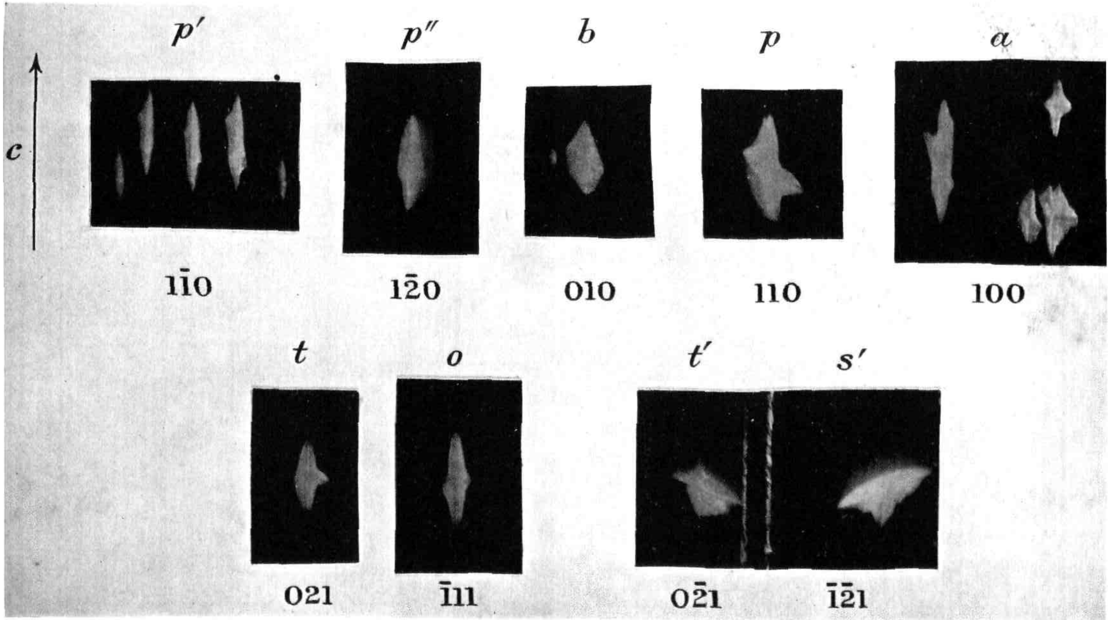
Face.	Angles of subsidiary growth with *c* axis.	Crystal direction.	Calculated angle.
p′(1$\bar{1}$0)	31° 30′	[114]	26°
p″(1$\bar{2}$0)	33°	[214]	33°
b(010)	303°	[101]	305°
	51°	[$\bar{2}$01]	51°
p(110)	56°	[$\bar{1}$11]	54°
a(100)	87°	[010]	82°
	28—54°		

The crystal directions are given in zone axis symbols, and indicate the directions of growth starting from 0, 0, 0. The agreement between the calculated and the experimental values, except for the *p*′ and *a* faces, is within experimental error. Growth along the *a* axis is never observed, and in only one case is there growth in the direction of the *c* axis.

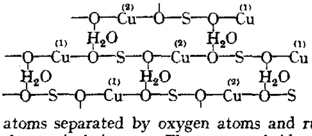
For the determination of the above crystal directions, use was made of a model of the X-ray structure as determined by Beevers and Lipson, and also of a wire model representing the crystal edges, as shown in Fig. 227 (Tutton, " Crystallography," 1922).

Discussion.

The arrangement of the copper and sulphate ions and the water of crystallisation in the crystal has been determined by Beevers and Lipson (*loc. cit.*). The copper ions are arranged


c
p′
1$\bar{1}$0
p″
1$\bar{2}$0
b
010
p
110
a
100
t
021
o
$\bar{1}$11
t′
0$\bar{2}$1
s′
$\bar{1}\bar{2}$1

in a face-centred pattern in the 001 plane and are each co-ordinated with four water molecules and two oxygen atoms from near-lying sulphate groups. If a direction parallel to the *a* axis be considered, it is seen that the copper ions are arranged in rows, and that the co-ordinated groups of alternate rows of copper ions have different configurations. Also, the members of alternate rows are differently placed with respect to the sulphate groups. The fifth water molecule is co-ordinated with two oxygens and two other water molecules, and is more firmly bound than the four water molecules co-ordinated to the copper ions. A conventional diagram which shows roughly how the atoms in the 001 plane are linked together is shown below. The three-dimensional diagram of the lattice structure can be seen in the paper of Beevers and Lipson (*loc. cit.*, Fig. 2). The horizontal rows consist of copper



(1 and 2) and sulphur atoms separated by oxygen atoms and run diagonally across the 001 plane in the form of a vertical zig-zag. The rows are bridged by the fifth water, and there is nothing to indicate that alternate coppers 1 and 2 are in any wise different from one another. The layer is, however, much distorted and crumpled by the valency angle requirements, and the crumpling causes alternate coppers to take up different configurations in the crystal. The layers in the 100 plane are held together in the direction of the *c* axis by the water molecules co-ordinated to the copper.

Dehydration can occur in three stages, giving the trihydrate, monohydrate, and anhydrous salt. Under the conditions of our experiments, *viz.*, nuclei formation in high vacuum, the dehydration proceeds rapidly to the monohydrate, and the existence of the trihydrate is only observed at temperatures above 50° (cf. Garner and Tanner, J., 1930, 47). Therefore we shall consider only the case of the direct dehydration from the pentahydrate to the monohydrate. This means the removal of the four water molecules co-ordinated to copper, which hold the layers together, and their removal must cause the collapse of the lattice in the direction of the *c* axis. The subsequent rearrangements of these layers are unknown, since the *X*-ray structure of the monohydrate has not been determined.

Since the water is liberated at an interface on one side of which is the pentahydrate lattice and on the other the collapsed lattice, it is clear that the direction of most rapid movement of the water molecules will depend to some extent on the structure of the collapsed lattice. If the layers in the 001 plane collapse in the direction of the *c* axis, then a possible consequence is that the escape of water along the 001 plane might be hindered. This would cause growth along this plane to be relatively slow. On the other hand, such a collapse might leave the avenues of escape for water molecules still open in the direction of the *c* axis. This would account for the dominant rate of growth along the *c* axis. It is clear that the structure of the collapsed lattice will play a dominant rôle in the dehydration phenomena, but until its nature has been made clear by *X*-ray analysis it is not worth while to discuss its possible contributions in any detail.

A study of the crystal model, however, shows that the greatest density of copper ions occurs in the 010 plane, and this is the plane in which the haloes lie. It is, therefore, probable that water molecules during dehydration pass from copper ion to copper ion along this plane until they reach the surface of the crystal. The activation energy required for this transference will depend on the arrangement of the copper ions and water molecules in the lattice, and will be expected to be smaller the closer the copper ions are to one another. There is little known about the change of activation energy with direction. An isolated observation by Bright, that the temperature coefficient of growth of the smaller horn on the *p* face is greater than that of the longer horn, is perhaps an indication that the activation energies are different in different directions.

On the *b* face, the distance between the copper ions along the *c* axis is 5·97 A., whereas along the *a* axis it is 6·12 A. Nuclear growth is slower along the *a* than the *c* axis, and this

is in agreement with the view that the distance apart of the copper ions plays a part in the transference of water. However, growth in a diagonal direction across the *b* face, where the copper distance is 7·2 A., is greater than in the direction of the *a* axis. This shows that distance apart of the copper ions is not the only factor involved. Also on the *p* face, the most prominent direction of growth is along the *c* axis. Growth in the 001 plane, where the copper ion distance is 6·7 A., is not specially marked, but there is a marked subsidiary direction of growth where the distance is 7·7 A. Here, again, it is clear that there is some inhibition acting in the direction of the 001 plane. Similar considerations apply to the *p'* face. On the other hand, for the *a* face, where the 001 plane cuts the face along the *b* axis, growth does not appear to be inhibited in the 001 plane. The inhibition only applies to the *a* axis and directions lying between the *a* and the *b* axis. A special case of inhibition of growth occurs on the *t*, *t'*, and *s'* end faces, where the growth of the halo and the resulting lattice changes inhibit the formation of a horn above it.

The process of dehydration is to a certain extent reversible, otherwise a steady dissociation pressure would not be obtained at constant temperature. Thus in considering the shape of the nuclei, the rate of return of the water molecules to the interface must be taken into account. Even in a high vacuum some of the molecules leaving the interface will diffuse backwards and thereby decrease the rate of dehydration. The rate of return will naturally depend on the magnitude and the sign of the curvature of the interface, which in some of the nuclei vary enormously. The high positive curvature at the tips of the horns of these nuclei will cause an increased rate of return of the water molecules to the interface. Consequently, the rate of dehydration will be reduced and thereby cause the tips of the horns to possess a rounded appearance.

It is therefore concluded that the shapes of the nuclei are controlled by three factors: (1) the activation energy for the removal of the water molecules, which will vary with direction; (2) the collapse of the lattice, which will hinder the escape of water in certain directions; and (3) the curvature of the interface, which affects the rate of return of water molecules to the interface.

Our thanks are due to Imperial Chemical Industries for a grant for the purchase of apparatus.

THE UNIVERSITY, BRISTOL. [*Received, May 27th*, 1937.]

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328. *Reaction Chains in the Decomposition of Organic Compounds.*

By L. A. K. STAVELEY and C. N. HINSHELWOOD.

The primary act in the decomposition of an organic molecule can be either an internal rearrangement to stable products, or the production of free radicals which may cause further decomposition by a chain process. In some examples both mechanisms operate simultaneously.

Nitric oxide inhibits certain types of gas reaction, an effect attributed to its power of combining with such free radicals as may be formed. This provides a method for determining the relative importance of the two separate reaction mechanisms.

The present paper summarises the evidence which this method has yielded about the conditions determining the production and chain propagating efficiency of free radicals in various organic decompositions.

In many reactions the contribution from the chain processes is negligible. In others it appears that a small proportion only of the primary acts yield radicals, but that these may in some circumstances give rise to long chains.

The recognition of the part played by radicals does not necessitate any fundamental change in our views about the mechanism of activation in unimolecular reactions.

IN reactions such as the decomposition of dimethyl ether two processes are potentially in competition. The first is a rearrangement to give saturated products:

$$CH_3{\cdot}O{\cdot}CH_3 = CH_4 + H{\cdot}CHO.$$

The second is the production of free radicals :

$$CH_3{\cdot}O{\cdot}CH_3 = CH_3 + OCH_3,$$

a change which, although occurring much more rarely, has profound consequences, since the radicals may cause the secondary decomposition of many molecules. Whether, in a given example, the subsequent disturbances are enough to compensate for the rarity of the primary process is a matter which only experiment can decide.

Nitric oxide inhibits certain types of gas reaction. The best explanation is that it suppresses reaction chains by combining with free radicals. This effect may be used to investigate the part played by chains in the decomposition of simple organic substances, a problem which has been much discussed in recent years, but in which unambiguous experimental evidence has been largely lacking. This paper summarises the more direct evidence so far obtained by the use of nitric oxide as a chain indicator about the molecular processes involved in these reactions. [Papers from this laboratory will be referred to by the following letters: (*a*) Staveley and Hinshelwood, *Nature*, 1936, **137**, 29; (*b*) *idd.*, *Proc. Roy. Soc.*, 1936, *A*, **154**, 335; (*c*) *idd.*, J., 1936, 812; (*d*) Hinshelwood and Staveley, J., 1936, 818; (*e*) Mitchell and Hinshelwood, *Proc. Roy. Soc.*, 1937, *A*, **159**, 32; (*f*) Staveley and Hinshelwood, *ibid.*, p. 192. These papers contain references to the work of Paneth, Rice and Herzfeld, Patat and Sachsse, Leermakers, and others which need not be repeated here.]

About the nature of the action by which radicals propagate chains two views are possible. The radical may actually remove some portion of the molecule which it attacks, leaving an unstable residue which then breaks down giving a stable product and regenerating a radical similar to the original one. On the other hand, it may simply cause such a disturbance in the molecule which it approaches that the latter is more easily rearranged into stable products, and gives these with a much lower activation energy than it would normally require. According to this view, the chain is simply the series of molecules, the catalytic decomposition of which is brought about by one radical during its lifetime. That free radicals should exert some such action might be expected theoretically (cf. Eucken and Jaacks, *Z. physikal. Chem.*, 1935, *B*, **30**, 85).

Types of Reaction subject to Inhibition by Nitric Oxide.—The accompanying table provides a synopsis of the reactions examined, and includes some hitherto unpublished results.

It will be observed that all the ethers are subject to inhibition, but that the effect diminishes rapidly as the homologous series is ascended (ref. *f*). With chloral and acetaldehyde, the results are negative, but the effect appears with propaldehyde and in an increased degree with butaldehyde. Considerable inhibition is found with ethane (unpublished results of Staveley), but, rather remarkably, ketones are exempt, as also is methyl alcohol. All these reactions are predominantly homogeneous under the conditions of the experiments. In this connexion the negative result with the purely heterogeneous reaction of methyl formate is interesting in that it helps to dispose of the suggestion that one function of the nitric oxide is to poison the walls of the vessel.

Mean Chain Lengths.—We have called the ratio of the rates of the uninhibited and fully inhibited reactions the mean chain length. According to this convention a molecule which decomposes by a pure rearrangement process, giving no radicals to bring about further decomposition, is regarded as giving a chain of unit length. Thus a mean chain length of 4·4 with diethyl ether might mean that every primarily decomposing molecule gives radicals which cause the decomposition of about three or four more, or that only one in 100, say, of the primary processes gives radicals, but that these cause the decomposition of about 350 molecules. The average length of the chains derived from those molecules which do in fact yield the radicals we may call the *absolute* chain length.

Two arguments lead us to believe that this absolute chain length is high. First, the energies required to break the carbon–carbon and carbon–oxygen bonds, although not known exactly, are undoubtedly considerably greater than the activation energies of the chain-free reactions, as may be seen from the table. Therefore the number of primary processes giving free radicals must be a small fraction only of those in which rearrangement occurs, so that for an appreciable mean chain length the absolute length must be con-

siderable. Quantitative calculations on this basis are useless until bond energies are known more accurately. Secondly, nitric oxide is consumed in the course of the reactions which it inhibits. If we can assume, on the basis of photochemical experiments made at lower temperatures (ref. *e*), that one molecule is used up for each chain broken, then the absolute length can be estimated. For dimethyl ether (ref. *f*) it comes out to be 400. This, however, is really a lower limit, since, at the high temperatures employed, nitric oxide is almost certainly removed in oxidation reactions distinct from the chain-breaking processes. An upper limit, on the other hand, is set to the absolute chain length by the absence of any

Substance.	Effect of small amounts of NO on the decompn.	Mean chain length.	Activation energy of the chain-free reaction.	Activation energy of the chain-propagating reaction.	Bond strength.	Number of square terms needed to account for rate of chain-free reaction.
Hydrocarbons.						
Ethane	Inhibition	21 (600°) 50 mm. 6 (600°) 500 mm.	74,500	10,000	~80,000	—
Ethers.						
Dimethyl	Inhibition	17 (540°)	62,000	12,000	~82,000	10
Methyl ethyl	,,	8·4 (540°)	62,000	12,000	—	10
Diethyl	,,	4·4 (540°)	67,000	10,000	—	18
Ethyl propyl	,,	3·2 (540°)	—	—	—	—
Dipropyl	,,	2·7 (540°)	60,500	—	—	17
Diisopropyl	,,	1·4 (540°)	65,500	—	—	>24
Aldehydes.						
Acetaldehyde	No inhbtn.	1·0	46,000	10,000	~84,000	2
Propaldehyde	Inhibition	2·3 (549°) 159 mm. 3·9 (549°) 30 mm.	56,000 350 mm. 63,500 30 mm.	8,000	~80,000	6 350 mm.
Butaldehyde	Inhibition	3·5 (500°) 100 mm. 6·0 (500°) 30 mm.	55,500 100 mm.	—	~80,000	—
Chloral	No inhbtn.	1·0	49,000	—	—	—
Ketones.						
Acetone	No inhbtn.	1·0	68,000	—	~84,000	—
Methyl ethyl ketone	,,	1·0	—	—	—	—
Esters.						
Methyl formate	,,	Heterogeneous	—	—	—	—
Alcohols.						
Methyl alcohol	,,	1·0	68,000	—	~84,000	12

The iodine-catalysed decompositions of aldehydes and ethers are not inhibited by nitric oxide (Mitchell, unpublished experiments).

marked retardation of the reaction by the packing of the vessel. The effects found are not more than of the order 10—20%, and are never in any way comparable with those observed in reactions such as the combination of hydrogen and oxygen. In view of the sensitiveness of the rates to small temperature errors, the effects are almost too small to be regarded as significant at all in the absence of independent evidence.

Factors determining the Occurrence of Chains.—The contrast between acetaldehyde, which at 500—600° undergoes the change $CH_3{\cdot}CHO = CH_4 + CO$ without the appearance of free radicals, and that of ethane, which at somewhat higher temperatures suffers the decomposition $C_2H_6 = C_2H_4 + H_2$ with the intervention of enough radicals or atoms to give a mean chain length as great as 20, is striking enough to merit discussion.

Two factors are important. One is the relative ease of two competing processes: the rearrangement in one act into stable products, and, on the other hand, the splitting into radicals. The other factor is the efficiency with which the latter cause further decomposition. If the activation energy for the rearrangement is smaller than the bond energy by a great enough margin, no free radicals will be produced except at temperatures where

the reaction velocity is too great to be measured. This seems to explain the contrast between acetaldehyde and ethane, since the observed activation energies are 46,000 and 74,500 cals. respectively. The energy required to break the C–C bond being of the order 80,000 cals., with acetaldehyde the competing rearrangement process has an advantage of about 30,000 cals., while with ethane the advantage cannot be more than a few thousand cals. This explanation is confirmed by the fact that artificially introduced radicals cause a decomposition of acetaldehyde with an activation energy of only about 10,000 cals., which is comparable with the value for ethane (Leermakers, and ref. *e*: also Staveley, unpublished results).

The activation energies for the reactions between the radicals and the original substance, which measure the ease of propagation of the chain, are obtained in two ways, which give concordant results: (1) from photochemical measurements (ref. *e*), and (2) from measurements of the amount of nitric oxide required to reduce the rate of the thermal reaction in a given ratio. The values, which are approximate only, vary from 8,000 to 12,000 cals.

Propaldehyde shows an interesting transition between ethane and acetaldehyde. The curve relating reaction rate and pressure has the segmented appearance due to the superposition of processes involving different species of activated molecules. One of the segments with propaldehyde is attributed to a mode of reaction where the activation energy is localised in the ethyl group. By the nitric oxide method it is found that the activated molecules belonging to this species alone produce a detectable proportion of radicals. When the chains due to these are suppressed, the rate-pressure curve becomes exactly like that for acetaldehyde, a fact which in itself is a confirmation of our interpretation of the nature of these curves. The mean activation energy for the chain-yielding mode is several thousand calories more than that for the others. The fact that the proportion of radicals rises from zero to a finite value as the activation energy increases is another example of the general principle already illustrated by the contrast of acetaldehyde and ethane. With butaldehyde where the alkyl group is larger than with propaldehyde, the mean chain length is still greater.

With the ethers, the activation energies for the rearrangement processes are from 60,000 to 68,000 cals., being thus 10,000—20,000 cals. lower than the bond energies. If it is assumed as a rough approximation that the probability of the two competing modes of decomposition is determined only by the activation energies, not more than one in some hundreds of the primarily decomposing molecules gives radicals. The mean chain length being a few units, the absolute length must be 2—3 powers of 10. By assuming a value of this order, the concentration of free radicals can be estimated. The energy of activation of the propagation process is such that the radical causes the decomposition of only one ether molecule in several hundred: thus the radical must meet 10^5—10^6 ether molecules in the course of its life. If its final removal occurs in a binary collision with another radical present at comparable concentration with itself, then this concentration must be 10^{-5}—10^{-6} of the ether concentration. At 829° Abs., in the inhibited decomposition of diethyl ether, 4×10^{15} molecules react per c.c. per second when the initial pressure is 200 mm. If about 10^{-3} of this number give radicals, the rate of production is of the order 4×10^{12} per c.c. per sec. These must be removed by recombination. At the estimated concentration the number of binary collisions exceeds 10^{15}, which is great enough to allow us to assume an even greater absolute chain length without improbability

The activation energy for acetone is even higher than that of the ethers, yet there are no chains. It would seem, therefore, that their absence is due to the insensitiveness of the acetone molecule to the action of radicals. This is, in fact, confirmed by experiments on the artificial introduction of radicals (Rice, Rodowskas, and Lewis, *J. Amer. Chem. Soc.*, 1934, **56**, 2497). The acetone molecule is also insensitive to the action of iodine, which causes the decomposition of ethers, aldehydes, and esters.

Variation of Chain Length with Temperature.—The essential steps in the chain process must be: primary radical formation; propagation; chain breaking, which may be simply represented as follows:

$$(1)\ XY = X + Y;\quad (2)\ X + XY = \text{Products} + X;\quad (3)\ 2X = X_2.$$

Let k_1, k_2, and k_3 be the velocity constants of these reactions. Writing down the equation for a stationary concentration of X, we find that for a given concentration of XY the rate is proportional to $k_2(k_1/k_3)^{\frac{1}{2}}$, whence $E_{obs.} = E_2 + \frac{1}{2}E_1 - \frac{1}{2}E_3$, where E_3 is probably quite small, and will be neglected, though our final conclusions are not affected by doing so. Whether or not the apparent chain length of a reaction in which both radical chains and direct rearrangements occur increases or decreases with rise in temperature depends upon whether $E_2 + \frac{1}{2}E_1$ is greater or less than E_0, the value for the rearrangement. Since $E_1 > E_0 > E_2$, the sign of $E_2 + \frac{1}{2}E_1 - E_0$ is evidently a matter of numerical accident. There is thus no great theoretical significance in the fact that with the ethers the apparent chain length increases slightly as the temperature falls, whereas with propaldehyde it decreases. Elaboration of the reaction scheme will leave the general lines of the above argument unchanged.

Variation of Chain Length with Pressure.—With diethyl ether the mean chain length varies little in the range 50—500 mm. With propaldehyde it falls as the pressure increases, but for a special reason, already discussed, connected with the nature of the rate–pressure curve itself. For ethane the apparent chain length falls from 21 at 50 mm. to 6 at 500 mm.

Theory predicts a great variety of possible behaviours. Each of the two primary processes, the rearrangement reaction and the radical formation, is unimolecular with its own pressure dependence. There are two important kinds of chain-breaking reaction: recombination of radicals in binary collisions, and recombination with the intervention of a third molecule. To account for the decrease of chain length with increasing pressure in the case of ethane, detailed calculation shows that we must make one of two assumptions. One is that the rate of the radical-yielding process varies less rapidly with pressure than that of the competing process. In this case the assumption of either binary or of ternary collisions would be possible for the recombination process. On the other hand, we can assume that the two primary processes have the same pressure-dependence, in which case the assumption of ternary collisions for the recombination process cannot be avoided. A definite decision between the two possibilities cannot be reached on the evidence of pressure-dependence alone. It would be interesting to analyse the problem further, since, in the photochemical decomposition of acetaldehyde it appears clearly from the kinetics that the recombination of the methyl radicals is a bimolecular process, and if the chains in the ethane reaction are ended by a termolecular process, then it would suggest that, not methyl radicals, but hydrogen atoms are concerned.

Function of the Nitric Oxide.—Nitric oxide contains an odd number of electrons and is therefore virtually a free radical itself. It might therefore be expected to combine with other free radicals, and is in fact known to combine with hydrogen atoms. The primary product would presumably be a nitroso-compound which would very rapidly undergo further reactions. It is known that nitric oxide oxidises organic compounds and is itself reduced to nitrogen or ammonia. Thompson and Meissner have, in fact, observed spectroscopically the formation of ammonia during the decomposition of dimethyl ether in presence of nitric oxide. There must be a complicated series of reactions leading to these end-products. If nitroso-compounds are formed, they might isomerise to oximes which would lose water giving cyanides. Cyanides do not, however, appear in detectable amounts. Although the subsequent changes are complicated and largely unknown, on general grounds there can hardly be any doubt that the actual chain-breaking process is the combination of the radical with the nitric oxide.

The Theory of Unimolecular Reactions.—The question arises how far the existence of unsuspected chain processes vitiated earlier conclusions about the mechanism of activation in unimolecular reactions. It may be said that our views on this matter require no substantial modification. In the first place, reactions such as the decomposition of acetone appear to involve no chains. Secondly, experiments on the suppression of chains with nitric oxide have shown that the characteristics of the residual processes are still those normally accepted as distinguishing unimolecular reactions.

The evidence may be summarised as follows:

(1) The variation of rate with pressure for the inhibited decompositions of ethers is the same as that for reactions free from chains (*b*, *c*, *f*).

(2) To account for the observed rates of the inhibited reactions the activation energy must still be assumed to be distributed in many square terms (*f*). For a series of ethers the number of square terms bears a more natural relation to the structure of the molecule than it appeared to do before the interference by chain processes was allowed for.

(3) In the study of propaldehyde it was inferred that the radicals arose only from certain types of activated molecule : this is itself evidence in support of the earlier conclusion that different modes of activation contribute to the reaction (*c*, *d*).

(4) The characteristic influence of hydrogen is found with the inhibited decompositions of diethyl ether and of propaldehyde (*d*).

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[*Received, June* 24*th*, 1937.]

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329. *The Functional Relation between the Constants of the Arrhenius Equation. Solvent Effects in the Formation of Quaternary Ammonium Salts.*

By R. A. Fairclough and C. N. Hinshelwood.

Reaction velocity can be expressed in the form $PZe^{-E/RT}$, where E is activation energy, Z the collision number, and P a probability factor, the nature of which forms the subject of various recent investigations. In a previous paper correlations between E and log PZ for various series of reactions were studied experimentally and theoretically. In the present paper the formation of methylpyridinium iodide is studied in binary mixtures of various solvents. The variations of PZ with solvent composition are of diverse and complicated types, in spite of which it is found that they can be analysed into a general correlation between log PZ and E together with a uniform tendency for PZ to increase with the polarity of the solvent.

In a previous communication (this vol., p. 538) the correlation existing for many reactions between the quantities E and log PZ of the Arrhenius equation was discussed. A simple relation was found to hold for change of solvent in many cases. In the formation of quaternary ammonium salts, two effects appeared to be superimposed, namely, the normal correlation between E and log PZ through a series of solvents of approximately the same polarity, and a general tendency for P to increase in the more polar solvents.

The object of the experiments to be described was to confirm and extend these conclusions. The plan was to study the variations of E and of log PZ for the formation of methylpyridinium iodide in binary solvent mixtures of different types, including polar–polar and polar–non-polar systems. The activation energy varies with solvent composition according to curves of diverse and occasionally complicated form (Fig. 1). The form of the curves for log PZ against composition tends to follow that of the corresponding activation energy curve, showing that the correlation between log PZ and E is at least one important factor (see continuous lines in Figs. 2—6). By assuming the form of correlation found to hold in the previous paper for many reactions, all the values of log PZ can be reduced to correspond to a standard activation energy. If no other factor were involved, the reduced values would all be the same. Actually they vary, but the residual variation is of the same simple form in each case, being a steady and regular increase with increasing solvent polarity. The fact that widely divergent types of behaviour can all be reduced in this way to a single simple form of variation justifies the suggested analysis of the effect into two factors. It is therefore concluded that the functional relation between E and log PZ previously advanced applies generally to solvent changes in the formation of quaternary ammonium salts, but that, in addition to the changes of log PZ produced in this way, there is also a variation which is independent of the energy of activation, but dependent on the polarity of the solvent.

Experimental Results.—The general procedure was that described in the previous paper. The various solvents were fractionated in an all-glass apparatus after being dried with

Fig. 1.

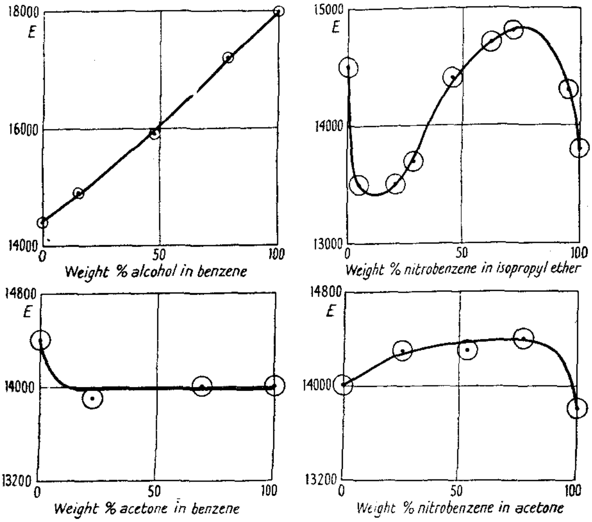
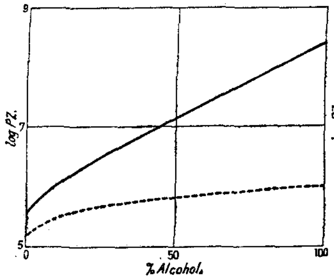
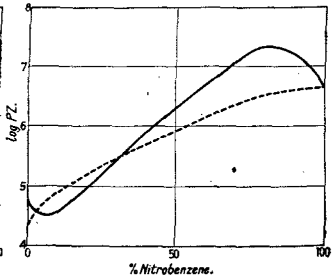


Fig. 2.



Alcohol–benzene.

Fig. 3.



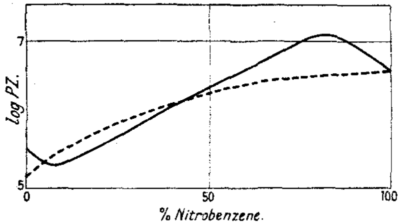
iso*Propyl ether–nitrobenzene.*

appropriate agents (sodium for benzene and *iso*propyl ether, lime for alcohol, and calcium chloride for nitrobenzene).

In calculating velocity constants, correction was made for thermal expansion of solvents. Activation energies were determined from measurements at four temperatures in the range

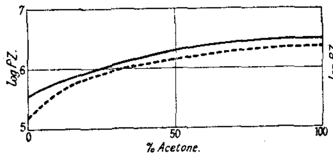
either 25—80° or 40—100°. In general, we estimate their accuracy to be of the order ± 150 cals.

FIG. 4.



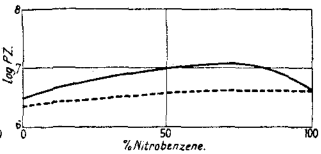
Benzene–nitrobenzene.

FIG. 5.



Acetone–benzene.

FIG. 6.



Acetone–nitrobenzene.

The following tables give the values of E and of log PZ for the various systems.

Alcohol–Benzene.

EtOH, wt. %.	E.	log PZ.
0	14,400	5·55
15·5	14,900	6·28
47·5	15,900	6·99
78·3	17,200	7·86
100	18,000	8·32

Acetone–Nitrobenzene.

$Ph\cdot NO_2$, wt. %.	E.	log PZ.
0	14,000	6·49
25·3	14,300	6·80
53·4	14,300	6·92
77·5	14,400	7·08
100	13,800	6·63

Benzene–Nitrobenzene.

$Ph\cdot NO_2$, wt. %.	E.	log PZ.
0	14,400	5·55
8·35	13,700	5·32
31·2	13,600	5·88
50·5	13,900	6·38
73·2	14,500	6·95
93·2	14,200	6·83
100	13,800	6·63

Acetone–Benzene.

$COMe_2$, wt. %.	E.	log PZ.
0	14,400	5·55
22·9	13,900	5·96
69·2	14,000	6·44
100	14,000	6·49

*iso**Propyl ether–Nitrobenzene.*

$Ph\cdot NO_2$, wt. %.	E.	log PZ.
0	14,500	4·77
5·2	13,500	4·53
21·6	13,500	5·03
29·2	13,700	5·37
45·2	14,400	6·03
62·3	14,700	6·57
71·3	14,800	7·12
94·8	14,300	6·97
100	13,800	6·63

Discussion.—Fig. 1 shows the variation of activation energy with composition for four systems. The system benzene–nitrobenzene, which is not plotted, closely resembles that of *iso*propyl ether–nitrobenzene. The remaining figures show the variations of log PZ, which are generally similar to those of E.

To reduce the log PZ values to correspond to a standard activation energy the following procedure was adopted. The form of the correlation between E and log PZ was assumed to be that discussed in the previous paper, namely $d \log PZ/d(1/E^{\frac{1}{2}}) =$ constant. From the results of that paper the constant was taken to be approximately $- 0{\cdot}22 \times 10^4$. The value of E for pure nitrobenzene, 13,800, was taken as an arbitrary standard, and the observed values of log PZ were recalculated to what they would have been, according to the

formula, had the activation energies all been 13,800. The reduced values are shown plotted against composition in the diagrams (broken lines).

In each of the cases where a polar solvent is added to a non-polar solvent, the reduced values show a steady increase, and lead to curves of very similar form. Where two highly polar solvents are mixed, as with the system acetone–nitrobenzene, the reduced values of log *PZ* are almost constant.

With regard to the possible explanation of this increase of *PZ* with solvent, several factors may contribute. In the first place, the reduced variations are now of limited range and not outside conceivable variations in the actual encounter numbers. Secondly, if a ternary collision with a solvent molecule is necessary to stabilise the activated polar product and prevent its reversion into its components, then polar solvents may well be supposed to be more efficient in this respect. The same results would be achieved if the polar solvent molecules shortened the time which, according to the theory discussed in the previous paper, elapses on the average between activation and reaction.

We are not primarily concerned in this paper with the actual relations between the activation energy itself and the composition, but the curves in Fig. 1 call for the following remarks. The **S**-shaped curve is found in systems containing nitrobenzene and a non-polar solvent, but not in the system nitrobenzene–acetone, where a single maximum occurs. On the other hand, when acetone is added to benzene there is initially a sharp fall. If the initial fall is regarded as characteristic of the addition of a polar solvent to a non-polar one, then the **S**-shaped curves are probably to be interpreted as a superposition of the two types.

[*Received, June 24th,* 1937.]

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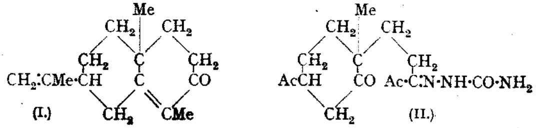
330. *Synthetic Cyperones and their Comparison with α- and β-Cyperones.*

By P. S. Adamson, F. C. McQuillin, Robert Robinson, and J. L. Simonsen.

Suitable methods for the synthesis of certain sesquiterpene derivatives were independently devised in our two laboratories, and the present joint communication deals with the application of both processes to the synthesis of substances structurally identical with α- and β-cyperones. The respective oximes, semicarbazones, and 2 : 4-dinitrophenylhydrazones of the natural and the synthetic ketones exhibit undepressed melting points on admixture and closely resemble one another in most respects. They show, however, certain optical and crystallographic divergencies, so that complete identity is not claimed. A close scrutiny of the experimental details will, however, lead to the conviction that these syntheses establish the correctness of the constitution of the cyperones which was put forward by Bradfield, Pritchard, and Simonsen (this vol., p. 763).

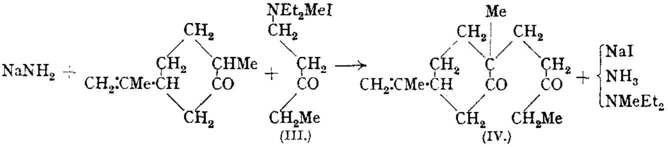
α-Cyperone is the name given to a ketone, $C_{15}H_{22}O$, prepared by hydrolysing a semicarbazone, m. p. 216°, in its turn obtained from the oil of the tubers of *Cyperus rotundus* (Hegde and Rao, *J. Soc. Chem. Ind.*, 1935, **34**, 387T; Bradfield, Hegde, Rao, Simonsen, and Gillam, J., 1936, 667); β-cyperone is obtained from the α-isomeride by the action of aqueous oxalic acid or methyl-alcoholic potassium hydroxide. Bradfield, Pritchard, and Simonsen (*loc. cit.*), revising earlier work in some particulars, showed that α-cyperone should be represented by the expression (I). On ozonolysis, β-cyperone semicarbazone gave the same



(I.) (II.)

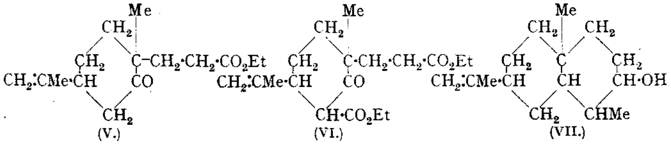
product, $C_{15}H_{23}O_4N_3$ (probably II), as the α-isomeride, and the conclusion was drawn that the αβ-isomerism is confined to the stereochemistry of the methyl and the isopropenyl

group. It is important to note that this evidence excludes isomerism due to a change in the position of the double bonds, and the formula (I) corresponds to no more than two optically inactive substances. In the oximes, semicarbazones, and dinitrophenylhydrazones there are naturally further possibilities of isomerism. Bradfield, Jones, and Simonsen (J., 1936, 1137) have already confirmed the essential correctness of (I) by a synthesis of a stereoisomeride of dihydrocyperone, and a similar process, described below, has now been extended to the synthesis of β-cyperone or a closely related stereoisomeride. Meanwhile, the unsaturated cyclic ketone synthesis of du Feu, McQuillin, and Robinson (this vol., p. 53) was being developed in a similar direction, so we decided to collaborate. The specimens of natural origin are designated Nα, Nβ; the synthetic specimens made in Bangor by way of the Reformatzky reaction are termed Bβ, and the synthetic specimens made by the more direct process in Oxford are termed Oα, Oβ.



(III.) (IV.)

We deal first with the latter section of the work. The condensation of the methiodide of 1-*diethylaminopentan*-3-*one* (III) and the sodio-derivative of *l*-dihydrocarvone was effected in ether–pyridine solution and afforded the solid *diketone* (IV). This was dehydrated with cyclisation by alcohol-free sodium ethoxide in benzene solution, with formation of a synthetic α-cyperone (Oα) (I), and by cold 50% sulphuric acid with formation of a synthetic β-cyperone (Oβ) (I). In the alternative method, the sodio-derivative of *l*-dihydrocarvone is condensed with ethyl β-chloropropionate with formation of *ethyl* 1-*methyl*-4-iso-*propenyl*cyclo*hexan*-2-*one*-1-β-*propionate* (V). This ester was purified by condensation



(V.) (VI.) (VII.)

with ethyl oxalate in alcoholic sodium ethoxide solution; the α-keto-ester lost carbon monoxide on heating, and the distilled product was doubtless *ethyl* 3-*carbethoxy*-1-*methyl*-4-iso*propenyl*cyclo*hexan*-2-*one*-1-β-*propionate* (VI). From this the keto-acid corresponding to (V) was obtained on hydrolysis, and the acid was then esterified.

When the ester (V) was treated with zinc and ethyl α-bromopropionate in toluene solution, a mixture of products was obtained, which was repeatedly fractionated with continuous fall of the boiling points. On hydrolysis of the main product with methyl-alcoholic potassium hydroxide, a ketone, $C_{15}H_{22}O$, closely resembling β-cyperone, was obtained (Bβ) (I). On reduction with sodium and alcohol this synthetic ketone afforded 1 : 10-*dimethyl*-7-iso*propenyldecal*-2-*ol* (VII), the 3 : 5-*dinitrobenzoate* of which showed no depression of melting point in admixture with α-cyperyl 3 : 5 dinitrobenzoate.

Comparisons.—The superficial physical characteristics of the natural and the synthetic cyperones are the same. In regard to Nα and Oα the densities, refractive indices, and boiling points are almost identical, but the rotatory powers are divergent; for example, Nα, $[\alpha]_{5461}$ + 138°; Oα, $[\alpha]_{5461}$ + 68°. The melting points of the oximes and semicarbazones are not the same (differences 6° and 12° in the respective pairs) but those of the appropriate mixtures in the case of the oximes were that of the less fusible specimen (Nα), and in the case of the semicarbazones the m. p. of Oα was raised by admixture with Nα. Miss D. M.

Crowfoot reports that the oximes Nα and Oα were practically indistinguishable morphologically.

Similar resemblances and divergencies were noted in the β-series. For instance, Nβ has $[\alpha]_{5461}$ + 239°, Oβ has $[\alpha]_{5461}$ + 342°, and Bβ had $[\alpha]_{5461}$ + 111·7°. It should be noted that Nβ and Bβ were regenerated from the semicarbazones, whereas Oβ was not subjected to this treatment, and it would appear that racemisation of this ketone occurs with surprising facility. Again, the derivatives, *viz.*, the oximes, semicarbazones, and 2 : 4-dinitrophenylhydrazones, showed, on appropriate admixture, mixed melting points which were always intermediate between those of the individual specimens.

The semicarbazones Oβ, Bβ, and Nβ had practically identical melting points and undepressed mixed melting points, and moreover the rotatory powers were not very different: $[\alpha]_{5461}$ + 201° and + 217° for Oβ and Nβ respectively. On the other hand, Miss Crowfoot found all five semicarbazones to be crystallographically different, although polymorphism was not excluded. For other comparisons the experimental section may be consulted, but the conclusion we have reached is that our synthetic ketones are structurally identical with the natural compounds, the position being complicated by ready racemisation or partial racemisation.

EXPERIMENTAL.

1-*Diethylaminopentan-3-one*.—β-Chloroethyl ethyl ketone (E.P. 282,412; Kenner and Statham, *Ber.*, 1936, **69**, 19) (40 g.) in ether (100 c.c.) was added dropwise to diethylamine (48 g.) in ether (200 c.c.) with stirring and cooling in ice. After several hours, dilute sodium hydroxide solution was added, the ether separated, and dried, and on distillation 1-*diethylaminopentan-3-one* (27·7 g.) was obtained, b. p. 84°/13 mm., $n_D^{15°}$ 1·4368 (Found: N, 8·8. $C_9H_{19}ON$ requires N, 8·9%). This substance when treated with methyl iodide, slightly in excess of the theoretical, with cooling, yielded the methiodide (III) as a very viscous fluid which could not be crystallised.

1-*Methyl-1-γ-ketopentyl-4-*iso*propenyl*cyclo*hexan-2-one* (IV).—*l*-Dihydrocarvone (32 g.) in ether (150 c.c.) was refluxed with powdered sodamide (9 g.) for 4 hours in a stream of dry nitrogen. 1-Diethylaminopentan-3-one methiodide (32·3 g.) in dry pyridine (50 c.c.) was then added dropwise with vigorous stirring. After the mixture had been kept overnight, the reaction was completed by refluxing for 5 hours. Water was added, the oil taken up in ether, and the extract dried and evaporated. On distillation of the residue, dihydrocarvone was first recovered, and a fraction then obtained, b. p. 146—150°/2 mm. (7·5 g.), which crystallised almost completely on cooling, and recrystallised from light petroleum in large, almost rectangular plates, m. p. 103° (Found: C, 76·8; H, 10·3. $C_{15}H_{24}O_2$ requires C, 76·3; H, 10·2%).

1 : 10-*Dimethyl-7-*iso*propenyl-$\Delta^{1(9)}$-octal-2-one and an Isomeride*.—(a) *Cyclisation of* (IV) *with sodium ethoxide*. The diketone, m. p. 103° (5 g.), was dissolved in dry benzene (50 c.c.), and alcohol-free sodium ethoxide (1·8 g.) added in small portions with shaking. After being kept for 24 hours at the room temperature, the brown solution was maintained at 60° for 1 hour; water was then added, and the benzene layer separated. The extract was dried and evaporated, yielding on distillation a pale yellow oil (3·2 g.), b. p. 160—163°/11 mm., $n_D^{14°}$ 1·5299, $d_{18°}^{18°}$ 1·012, $[\alpha]_{5780}$ + 68°, $[\alpha]_{5461}$ + 88° (Found: C, 82·3; H, 10·1. $C_{15}H_{22}O$ requires C, 82·6; H, 10·1%).

The *oxime* (Oα) crystallised from aqueous methyl alcohol in long needles, m. p. 144° (Found: C, 77·4; H, 10·0. $C_{15}H_{23}ON$ requires C, 77·3; H, 9·5%); mixed with the oxime of α-cyperone, m. p. 151°, it had m. p. 150—151°. The *semicarbazone* (Oα) crystallised from methyl alcohol in colourless, irregular plates, m. p. 202°, $[\alpha]_{5461}$ + 91·5° (in chloroform; *c*, 3·6) (Found: C, 69·6; H, 9·0. $C_{16}H_{25}ON_3$ requires C, 69·8; H, 9·1%); mixed with the semicarbazone of α-cyperone, m. p. 216°, it melted at 205—206°.

(b) *Cyclisation of* (IV) *with sulphuric acid*. The diketone, m. p. 103° (1·8 g.), was treated with cold 50% sulphuric acid with cooling and vigorous shaking. After standing for an hour, the liquid was kept at 50° for 30 minutes, then cooled and mixed with ice-cold water and ether. The extract was washed with dilute sodium carbonate solution, dried, and evaporated, and on distillation the residue afforded an almost colourless oil (1·2 g.), b. p. 130°/1 mm., $n_D^{16°}$ 1·5590, $d_{18}^{16°}$ 0·999, $[\alpha]_{5461}$ + 342° (Found: C, 82·6; H, 10·3. $C_{15}H_{22}O$ requires C, 82·6; H, 10·1%).

The *oxime* (Oβ) crystallised from aqueous methyl alcohol in long colourless needles, m. p. 152—153°, $[\alpha]_{5461}$ 147° in ethyl alcohol (*c*, 1·9) (Found: C, 77·3; H, 10·0; N, 6·1. $C_{15}H_{23}ON$ requires C, 77·3; H, 9·9; N, 6·0%). Mixed with the oxime of β-cyperone, m. p. 139°, it melted at 139°, and no depression occurred on admixture with the synthetic oxime (Bβ) described below. The *semicarbazone* (Oβ) crystallised from methyl alcohol in colourless prisms, m. p.

204° (decomp.), which rapidly turned yellow in the light; $[\alpha]_{5461}$ + 201° in ethyl alcohol (*c*, 2·2) (Found : C, 69·8; H, 9·2; N, 15·0. $C_{16}H_{25}ON_3$ requires C, 69·8; H, 9·1; N, 15·3%). Mixed with the semicarbazone of β-cyperone, m. p. 207°, it had m. p. 206° (decomp.), and a mixture of the semicarbazones Oβ and Bβ showed the same behaviour. The 2 : 4-*dinitrophenylhydrazone* crystallised from ethyl alcohol–ethyl acetate in scarlet prisms, m. p. 226° (Found : C, 62·8; H, 6·6; N, 14·1. $C_{21}H_{24}O_4N_4$ requires C, 63·3; H, 6·5; N, 14·1%). Mixed with the dinitrophenylhydrazone of β-cyperone, m. p. 218—219°, it melted at 222—223°.

Ethyl 1-*Methyl*-4-iso*propenyl*cyclo*hexan*-2-*one*-1-β-*propionate* (V).—A mixture of *l*-dihydrocarvone (60 g.) and sodamide (15·4 g.) in ether (800 c.c.) was refluxed for 10 hours, hydrogen being passed to remove the ammonia liberated. After cooling in ice, ethyl β-chloropropionate (54·8 g.) was added with vigorous shaking, sodium chloride separating. The reaction was completed by heating for 5 hours, ice was then added, the ethereal layer separated, dried, and the solvent evaporated. Distillation of the residual oil under 14 mm. pressure gave (i) *l*-dihydrocarvone (23 g.), (ii) b. p. 175—187° (41·5 g.), and (iii) b. p. 187—245° (12·5 g.).

To a cooled solution (salt-ice) of sodium (3·9 g.) in alcohol (90 c.c.) a similarly cooled mixture of the keto-ester (fraction ii) (43·3 g.) and ethyl oxalate (33·5 g.) was added. On being allowed gradually to attain the room temperature (48 hours), a brown solution was obtained, which was poured on crushed ice. The ethereal layer (A) was separated, the alkaline solution acidified with dilute sulphuric acid, and the resulting yellow oil dissolved in ether. The oil, remaining after the removal of ether from the dried solution, readily lost carbon monoxide on being heated for 1 hour (bath at 160—200°) at 18 mm., and then had b. p. 180—215°/3 mm. Redistillation gave *ethyl* 3-*carbethoxy*-1-*methyl*-4-iso*propenyl*cyclo*hexan*-2-*one*-1-β-*propionate* (VI) as a colourless viscid oil, b. p. 170—175°/3 mm., $[\alpha]_{5461}$ − 29·4° (in chloroform; *c*, 2·25) (Found: C, 66·8; H, 8·7. $C_{18}H_{28}O_5$ requires C, 66·7; H, 8·6%). The *semicarbazone* crystallised from aqueous alcohol in long needles, m. p. 147—148° (Found : C, 59·5; H, 7·9. $C_{19}H_{31}O_5N_3$ requires C, 59·8; H, 8·1%). From the neutral fraction of the oil (A) a further quantity of the ester was obtained on retreatment with ethyl oxalate.

Hydrolysis of the ester (60 g.) was effected by digestion with hydrochloric acid (270 c.c.) for 14 hours. The acid, which was a viscid oil, gave a *semicarbazone* crystallising from alcohol in well-formed cubes which were frequently twinned, decomp. 192—193°, after sintering at 184° (Found : C, 60·0; H, 8·1. $C_{14}H_{23}O_3N_3$ requires C, 59·8; H, 8·2%).

The acid (32·3 g.) was esterified with alcohol (320 c.c.) and sulphuric acid (57 g.) by heating for 20 hours; *ethyl* 1-*methyl*-4-iso*propenyl*cyclo*hexan*-2-*one*-1-β-*propionate* (V) had b. p. 181—182°/13 mm., $d_{25}^{25°}$ 1·003, $n_D^{25°}$ 1·4825, $[\alpha]_{5461}$ − 10·65° (in chloroform; *c*, 3·285) (Found: C, 71·0; H, 9·3. $C_{15}H_{24}O_3$ requires C, 71·4; H, 9·5%). The semicarbazone was an oil.

Condensation of the Ester (V) *with Ethyl α-Bromopropionate*.—1 : 10-*Dimethyl*-7-iso*propenyl*-$\Delta^{1(9)}$-*octal*-2-*one* (I). A mixture of the keto-ester (23·6 g.), ethyl α-bromopropionate (22·6 g.), and zinc (8·2 g.) in toluene (150 c.c.) was heated in an oil-bath, the vigorous reaction which ensued necessitating removal from the bath. After the reaction had moderated, the mixture was gently boiled (bath at 140—145°) for 15 hours. The zinc compound was decomposed with dilute sulphuric acid, the toluene separated and dried, and the solvent removed under diminished pressure. Distillation of the residual oil at 12 mm. gave three fractions : (i) b. p. up to 190° (1·8 g.), (ii) b. p. 190—200° (2·7 g.), (iii) b. p. 205—215° (19·3 g.). There was considerable decomposition during the distillation. Fractions (ii) and (iii), which gave with alcoholic ferric chloride brownish-green colorations, were repeatedly refractionated, during which process a continual fall in boiling point was observed; ultimately a large fraction, b. p. 170—190°/15 mm., was obtained.

This fraction, from several condensations (40 g.), was mixed with a methyl-alcoholic solution of potassium hydroxide (20 g.) and heated on the steam-bath for 2 hours; addition of water to the cooled solution caused the separation of an oil, which was collected in ether. Evaporation of the solvent from the dried solution gave the ketone, b. p. 170—180°/13 mm. (7·1 g.). From the alkaline solution the acid was recovered. This, after esterification, gave a further quantity of the ketone on treatment with ethyl α-bromopropionate in the presence of zinc. The ketone is also obtained in poor yield if the acid is digested with acetic anhydride, and the product distilled under diminished pressure.

For purification the ketone was converted into the *semicarbazone*, which was slowly deposited from the aqueous methyl-alcoholic solution; it crystallised from methyl alcohol in rosettes of colourless prisms, decomp. 209—210° after sintering at 195° (Found : C, 69·8; H, 9·1. $C_{16}H_{25}ON_3$ requires C, 69·8; H, 9·1%). It was highly phototropic, becoming bright yellow on exposure to light. On admixture with β-cyperone semicarbazone, decomposition occurred at 207—208°

after sintering at 195°. 1 : 10-*Dimethyl*-7-iso*propenyl*-$\Delta^{1(9)}$-*octal*-2-*one*, regenerated from the semicarbazone by digestion with oxalic acid in acetone solution and distillation in steam, was a colourless oil, b. p. 173—175°/14 mm., $d_{25°}^{25°}$ 0·9947, $n_D^{25°}$ 1·5565, $[\alpha]_{5461}$ + 111·7° (Found: C, 82·2; H, 9·9. $C_{15}H_{22}O$ requires C, 82·6; H, 10·1%). The *oxime* crystallised from methyl alcohol in long, fine needles, m. p. 141—144°, not altered by further crystallisation; $[\alpha]_{5461}$ + 112° (in alcohol; *c*, 2·035) (Found: C, 77·1; H, 9·6. $C_{15}H_{23}ON$ requires C, 77·3; H, 9·9%). In admixture with β-cyperone oxime it had m. p. 138°. The 2 : 4-*dinitrophenylhydrazone* crystallised from ethyl acetate–alcohol in red leaflets with a bright metallic reflex, m. p. 225—227°, not depressed in admixture with β-cyperone 2 : 4-dinitrophenylhydrazone, m. p. 218—219° (Found: C, 63·3; H, 6·5. $C_{21}H_{26}O_4N_4$ requires C, 63·3; H, 6·5%).

1 : 10-*Dimethyl*-7-iso*propenyldecal*-2-*ol* (VII).—The ketone (I) (2 g.) in alcohol (80 c.c.) was treated with sodium (8 g.). After completion of the reaction, water was added, the ethyl alcohol removed in steam, and the *decalol* collected in ether. Removal of the solvent left a very viscid oil (1·6 g.), b. p. 160°/12 mm., $n_D^{20°}$ 1·5032 (Found: C, 81·3; H, 11·7. $C_{15}H_{26}O$ requires C, 81·1; H, 11·7%). The 3 : 5-*dinitrobenzoate*, prepared by treating the alcohol with 3 : 5-dinitrobenzoyl chloride in pyridine solution, crystallised from alcohol in fine needles, m. p. 150—152° (*Found*: C, 63·8; H, 6·8. $C_{22}H_{28}O_6N_2$ *requires* C, 63·5; H, 6·7%). In admixture with α-cyperyl 3 : 5-dinitrobenzoate it had m. p. 150—153°.

On heating the alcohol with potassium hydrogen sulphate at 190—200° for 4 hours, elimination of water occurred and an oil, b. p. 148°/22 mm., was obtained. After distillation over sodium it had $d_{25°}^{25°}$ 0·9181, $n_D^{25°}$ 1·4992, $[\alpha]_{5461}$ + 47·0°, but analysis showed the *hydrocarbon* to be impure (Found: C, 86·6; H, 11·7. $C_{15}H_{24}$ requires C, 88·2; H, 11·8%). With hydrogen chloride, in either ether or acetic acid, it gave a liquid hydrochloride.

The following report has been furnished by Miss D. M. Crowfoot, to whom we are greatly indebted.

Oximes.—Five preparations were examined, *viz.*, those termed Nα, Oα, Nβ, Oβ, and Bβ. The first three were triclinic lath-shaped crystals on (001) elongated along (010). They were practically indistinguishable morphologically. *X*-Ray photographs [(010) " (001)] showed complete identity between Nα and Oα. There seemed to be a slight difference in the *c* spacing of the β-compounds when compared with the α-, though for the rest the photographs showed essential identity. The difference seems to be too small to indicate the presence of a different molecular species. It is more of the order of magnitude one would associate with the presence of a mixed crystal, mainly α. In any case it could not be due to a molecule with a completely different stereochemical configuration.

The synthetic β-specimens differed crystallographically from the above and also from one another. They were both orthorhombic, but the Oβ preparation showed positive birefringence, the Bβ negative. They may, however, be polymorphs, since from the melt in both cases orthorhombic negative crystals were obtained, but these were too small to be measured accurately.

2 : 4-*Dinitrophenylhydrazones*.—Three preparations were examined, *viz.*, Nα, Nβ, Oβ. All three were plates, lath-shaped on (001), elongated along (010), showing straight extinction and very marked yellow-red pleochroism. The birefringence was very high, the slow direction being along (001). The crystals were probably all orthorhombic. In the two β-preparations the plates were commonly bounded by the edges (110), (100), the angle between which was *ca.* 40′. The same angle was measured in the case of the α-preparation, though the crystals here, which were much stouter, were commonly bounded by (010) and (100). The morphological and optical evidence does not therefore distinguish between these three compounds; it would, of course, be possible to do so by the *X*-ray method.

Semicarbazones.—Five preparations were examined, *viz.*, Nα, Oα, Nβ, Oβ, Bβ and all were crystallographically different. Nα consisted of plates bounded by edges inclined at *ca.* 43° to each other; slow extinction along one edge. Through the plane of the plate a very much inclined biaxial figure is visible. Oα formed irregular plates through which a biaxial figure is visible with the acute bisectrix normal to the plane. The birefringence is positive. From the melt the crystals obtained from these preparations are very similar, but further evidence would be necessary to establish identity.

The three β-*semicarbazones* show very distinct forms. Nβ occurs as thick plates on (010) bounded by edges at an angle of 55°, the slow extinction lying in the acute angle at 35° to one edge. Through (010) a positive (or negative, optic axial very large) biaxial figure is visible showing γ nearly perpendicular to (010). The crystals may be monoclinic or triclinic.

Bβ forms thin lath-shaped plates, probably orthorhombic. The dispersion is extremely marked. Through the *c* face a negative biaxial figure with very small optic axial angle is

visible. Oβ forms lath-shaped, thickish plates. One eye of a biaxial figure is visible nearly normal to (001).

These three preparations were then studied on melting between two glass surfaces. All three decomposed visibly, and all crystallised in platy forms, of which that from Nβ and one of those from Bβ seemed possibly identical.

It is not possible to draw any definite conclusions as to the identity of any of these five semicarbazones until identical crystals have been obtained either from melts or from solutions, seeded if necessary.

We are indebted to the Government Grants Committee of the Royal Society for a grant. One of us (P. S. A.) desires to thank the Department of Scientific and Industrial Research for a maintenance grant.

University College of N. Wales, Bangor.
Dyson Perrins Laboratory, Oxford University. [*Received, July 24th*, 1937.]

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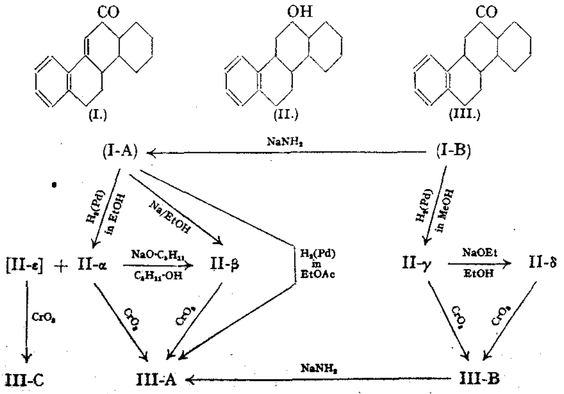
331. *Experiments on the Synthesis of Substances related to the Sterols. Part XVIII.*

By D. A. Peak and R. Robinson.

The condensation of the sodio-derivative of α-tetralone with acetyl*cyclo*hexene had already been found to yield three isomeric ketodecahydrochrysenes (A, B and C), of which A and B were recognised as stereoisomerides (Peak and Robinson, J., 1936, 759). These substances and their reduction products have been further examined with the result that further stereoisomerides of the latter have been characterised. It has been found possible to *C*-methylate a ketododecahydrochrysene in the angle position and similar work has been carried out with a ketomethoxyhexahydro*cyclo*pentanophenanthrene. In this way a stereoisomeride of oestratriene methyl ether has been synthesised.

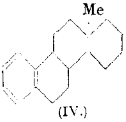
Preliminary experiments in connection with attempts to prepare *cyclo*pentane derivatives bearing the cholesterol side chain are also described.

We have already described (*loc. cit.*) two stereoisomerides of the formula (I) (and a third structural isomeride) and two secondary alcohols of the formula (II) which yield a single



ketone (III) on oxidation. Two new stereoisomerides of the formula (II) (γ and δ) have now been isolated and these on oxidation yield a second ketone (III). The catalytic reduction of I-A affords the known II-α and other substances not yet obtained in a pure condition. Oxidation of the crude by-products, however, gives a new ketone (III) and this points to the existence of a stereoisomeride, II-ε. The scheme on p. 1581 illustrates these relations and the substances newly characterised are II-γ, II-δ, III-B and III-C.

The keto-methylene group of 2-ketododecahydrochrysene-A (III) was found to be feebly reactive towards kationoid reagents (*loc. cit.*) and hence it was thought that *C*-methylation in the angle position (16) might be realised. Using potassium *tert.*-butoxide and methyl iodide in *tert.*-butyl alcoholic-ethereal solution, we were able to isolate a *methyl derivative*, which was reduced to a *methyldodecahydrochrysene* (IV) by the Wolff–Kishner method. On dehydrogenation of this with selenium, chrysene was produced, so the methyl group is undoubtedly in position 16. This conclusion is confirmed by the difficulty experienced in effecting dehydrogenation with platinum or palladium.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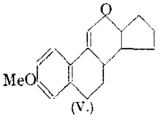
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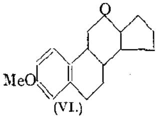
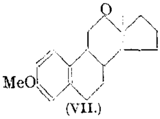

(VI.)

Rapson and Robinson (J., 1935, 1285) condensed the sodio-derivative of 6-methoxytetralone (better preparation described herein) with acetyl*cyclo*pentene and obtained 3-keto-7-methoxy-3 : 9 : 10 : 11-tetrahydro-1 : 2-*cyclo*pentanophenanthrene (V). This substance is now designated as isomeride-A, because two new isomerides-B and -C have been isolated as products of the same reaction. The absorption spectra indicate that the three substances are stereoisomerides (cf. Peak and Robinson, *loc. cit.*).

Catalytic hydrogenations of the isomerides-A and -B in ethyl acetate solution yielded the dihydro-derivatives -α and -β (VI) respectively. Both were *C*-methylated as already described and gave rise to stereoisomeric *3-keto-7-methoxy-2-methyl-*3 : 4 : 9 : 10 : 11 : 12-*hexahydro*cyclo*pentanophenanthrenes*-α and -β (VII). The α-isomeride did not form a semicarbazone readily, but the β-form behaved normally in this respect and was reduced by the Wolff–Kishner process with production of a *7-methoxy-2-methyl-*3 : 4 : 9 : 10 : 11 : 12-*hexahydro*-1 : 2-cyclo*pentanophenanthrene* (VIII), which is a stereoisomeride of oestratriene methyl ether (Cook and Girard, *Nature*, 1937, **133**, 377). On heating with selenium this substance suffered dehydrogenation, extrusion of the methyl group, and replacement of the methoxyl group by hydrogen; the product was 1 : 2-*cyclo*pentenophenanthrene.

We are much indebted to Miss D. M. Crowfoot for crystallographic and *X*-ray examination of the substance (VIII).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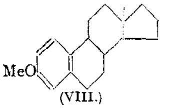
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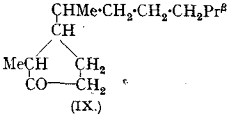


(IX.)

A description of some preliminary experiments along other lines is included in this communication and the bearing of such work on the problem has been sufficiently explained in previous parts of this series of papers. A new objective is the synthesis of the ketone (IX) and some of the matter of the experimental section is connected with this.

The chief point of general interest noted was the complete failure of G. M. Robinson's keto-acid synthesis when applied to *nordihydrocitronellic acid*, $CHMe_2\cdot[CH_2]_3\cdot CHMe\cdot CH_2\cdot CO_2H$ (see p. 1591). The chloride of the acid reacted normally with ethyl sodioacetylsuccinate, but on hydrolysis of the resulting ester, no keto-acid was formed and the *nor*dihydrocitronellic acid was recovered. The investigation is being pursued along other lines.

EXPERIMENTAL.

2-*Keto*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene-A* (III).—2-Ketodecahydrochrysene-A (2 g.) was shaken with palladised strontium carbonate (2 g. of 2%) in dry ethyl acetate (50 c.c.) in an atmosphere of hydrogen; about 1·3 mols. of hydrogen were absorbed. The filtered solution was concentrated, and the ketonic moiety isolated as the semicarbazone (1·3 g.). This was hydrolysed without further purification by boiling for a few minutes with dilute hydrochloric acid and the solid product was crystallised from ethyl alcohol, yielding the pure ketone (0·9 g.), m. p. 147—148° (Found : C, 85·05; H, 8·4. Calc. for $C_{18}H_{22}O$: C, 85·0; H, 8·7%). The semicarbazone had m. p. 231—233°. The preparation of this ketone by the oxidation of the related secondary alcohol was described in the previous paper (*loc. cit.*), but good analytical data were never secured. The m. p. of the pure substance as now obtained is only 1° higher than formerly, but the semicarbazone melts considerably higher.

2-*Keto*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene-C* (III).—2-Ketodecahydrochrysene-A (10·8 g.) was catalytically reduced with palladised strontium carbonate in methyl-alcoholic suspension. The crude product, after removal of the catalyst and solvent, was dissolved in glacial acetic acid (100 c.c.) and oxidised in the cold with a slight excess of chromic acid. The crude ketone-A which separated was collected, and the mother-liquors again treated with chromic acid. After keeping for 2 hours, the product was isolated by means of ether and crystallised from ethyl alcohol (100 c.c.), yielding 2-ketododecahydrochrysene-A (7·3 g.), pure after a further recrystallisation. The mother-liquors, on concentration to 20 c.c., deposited a further crop (1·3 g.), which was evidently a mixture. This was converted into a mixture of oximes. On digestion with cold concentrated hydrochloric acid, the *oxime* of dodecahydrochrysene-C dissolved, leaving the oxime of the isomeride-A undissolved. The former was recovered by dilution with water and recrystallised from ethyl alcohol, separating in stout prisms, m. p. 186—187·5° (Found : C, 81·0; H, 8·5; N, 5·6. $C_{18}H_{23}ON$ requires C, 80·3; H, 8·6; N, 5·2%). The m. p. was depressed to 179—183° by admixture with the ketoxime-A. The pure oxime was hydrolysed with boiling 20% aqueous oxalic acid; the ketone obtained separated from ethyl alcohol in hexagonal prisms, m. p. 87—88° (Found : C, 85·2; H, 8·4%).

2-*Hydroxy*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene-γ* (II).—2-Ketodecahydrochrysene-B (0·1 g.) was reduced by shaking with palladised strontium carbonate (1 g.) in methyl alcohol (50 c.c.) under 3 atm. pressure of hydrogen for 10 hours. The solvent was completely removed, and the residue crystallised from aqueous ethyl alcohol, from which it separated in aggregates of small needles, m. p. 155—156° (Found : C, 84·8; H, 9·3. $C_{18}H_{24}O$ requires C, 84·4; H, 9·4%).

2-*Hydroxy*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene-δ* (II).—The above isomeride-γ (44 mg.) was heated in a sealed tube with a solution of sodium (0·1 g.) in ethyl alcohol (2 c.c.) at 100° for 6 hours. The solution was then diluted with water, and the white solid collected and crystallised from ethyl alcohol, in which it was much less readily soluble than the other isomerides. It crystallised in small needles, m. p. 162—163° (Found : C, 84·6; H, 9·6%), depressed to 153—155° by addition of the isomeride-γ.

2-*Keto*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene-B* (III).—(a) The above isomeride-γ (38 mg.) was dissolved in the least amount of pure acetic acid, and a solution (0·11 c.c.) of chromic acid (1 g.) in water (1 c.c.) and acetic acid (10 c.c.) added. After standing overnight, the solution was diluted with water, the product crystallising in small needles which after recrystallisation from aqueous acetic acid had m. p. 114—115° (Found : C, 85·5; H, 8·9%). The m. p. was much depressed by addition of either of the isomerides A and C. The oxime crystallised from ethyl alcohol in small needles, m. p. 166—167°.

(b) The isomeride-δ (18 mg.), oxidised in the same manner, gave the same ketone, as shown by m. p. and undepressed mixed m. p.

Conversion of the Ketodecahydrochrysene-B into the Isomeride-A.—Isomeride-B (50 mg.) was heated with an excess of powdered sodamide in dry benzene (10 c.c.) for 6 hours. The yellow sodio-derivative and the excess of sodamide were decomposed with water, and the benzene layer evaporated to dryness. The residue separated from ethyl alcohol in the stout needles characteristic of isomeride-A, m. p. 198—199°, undepressed by admixture with pure isomeride-A.

Conversion of the Ketododecahydrochrysene-B into the Isomeride-A.—The isomeride-B (5 mg.) was treated as above in benzene (3 c.c.). The product crystallised from aqueous alcohol in needles. The amount was insufficient for recrystallisation, but the crude substance melted at 133—135° and the m. p. was raised to 140—146° by the addition of isomeride-A, which establishes its identity.

Dodecahydrochrysene.—The previously described decahydrochrysene obtained by Wolff–Kishner reduction of the semicarbazone of ketododecahydrochrysene-A was probably not homogeneous. A repetition of the experiment furnished the expected *dodecahydrochrysene*, crystallising from ethyl alcohol in needles, m. p. 83—84° (Found : C, 89·8; H, 10·1. $C_{18}H_{24}$ requires C, 90·0; H, 10·0%).

2-*Keto*-16-*methyl*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene.*—Potassium (0·8 g.; 5 atoms) was dissolved in *tert.*-butyl alcohol (15 g.), and dry ether (15 c.c.) added to the cold solution. 2-Ketododecahydrochrysene-A (1 g.) was then added. On addition of methyl iodide (10 g.) to the pale yellow solution potassium iodide was almost immediately precipitated; the reaction was completed by refluxing for 1 hour. Water was then added, and the ethereal layer separated and evaporated to dryness. The residue was dissolved in ethyl alcohol (5 c.c.); the solution gradually deposited crystals (0·2 g.). This material was recrystallised from ethyl alcohol, separating in stout prisms, m. p. 122—122·5° (Found : C, 85·3; H, 9·0; *C*-Me, 3·4, 3·7. $C_{18}H_{21}MeO$ requires C, 85·1; H, 8·9; *C*-Me, 5·6%. A control analysis of the unmethylated ketone gave *C*-Me, 0·5%).

The m. p. was depressed to 106—108° by admixture with the unmethylated ketone-A and also much depressed by the addition of the stereoisomeric ketone-*B*. The oxime crystallised from ethyl alcohol in needles, m. p. 222—224° (mixed m. p. with ketoxime-A, 215—220°). The semicarbazone crystallised from a large volume of boiling ethyl alcohol in small needles, m. p. 245—247° (mixed m. p. with the semicarbazone of ketone-A, 228—231°).

16-*Methyl*-1 : 2 : 3 : 4 : 5 : 6 : 7 : 8 : 13 : 14 : 15 : 16-*dodecahydrochrysene* (IV).—The above methylated ketone (1·0 g.) was converted into the semicarbazone (1·2 g.), and the latter heated for 20 hours in a sealed tube at 180° with a solution of sodium (0·8 g.) in ethyl alcohol (10 c.c.). After dilution with water, the semi-crystalline product (1·0 g.) was collected and well washed with water. The material, after distillation over sodium at 150°/3 mm., crystallised from aqueous ethyl alcohol in well-formed plates, m. p. 87—87·5° (Found : C, 89·5; H, 10·4; *C*-Me, 1·0. $C_{18}H_{23}Me$ requires C, 89·7; H, 10·3; *C*-Me, 5·9%. The corresponding unmethylated hydrocarbon gave *C*-Me, 0·6%; the low value for *C*-Me appears to be characteristic for fully saturated substances in this series). The m. p. was depressed by more than 20° by the addition of the unmethylated hydrocarbon.

Dehydrogenation of Methyldodecahydrochrysene.—(i) The hydrocarbon (50 mg.) was heated with selenium (0·25 g.) for 20 hours at 320—330°. No crystalline sublimate appeared until 10—12 hours had elapsed; the sublimate was thereafter repeatedly returned to the melt. The final crude sublimate was sublimed from sodium at 280°, yielding almost pure chrysene (10 mg.), m. p. 247—248°, alone or mixed with an authentic specimen. The *s*-trinitrobenzene complex crystallised in needles, m. p. 184—185°.

(ii) When the hydrocarbon was heated with a platinum-black of tested catalytic activity, dehydrogenation did not occur.

(iii) The hydrocarbon (0·1 g.) was heated at 300° in an atmosphere of carbon dioxide with palladised charcoal (0·1 g.) that was capable of effecting the complete dehydrogenation of the unmethylated hydrocarbon under the same conditions in 10 minutes. A crystalline sublimate appeared only after 4 hours, and gradually increased over a period of 10 hours. The sublimate, resublimed twice from palladised charcoal, melted at 247—248°, and at the same temperature when mixed with chrysene.

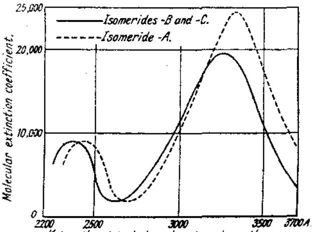
6-*Methoxy*-α-*tetralone.*—The following method of preparation of this ketone constitutes a considerable improvement on processes previously described. γ-*m*-Methoxyphenylbutyric acid (50 g.) was stirred with anhydrous stannic chloride (50 c.c.) at 100° for 1 hour. The deep red liquid was cooled and poured into cold dilute hydrochloric acid, and the resultant pale yellow oil washed free from stannic chloride by decantation, taken up in ether, and washed with dilute sodium hydroxide solution. The ethereal layer was dried over sodium sulphate and evaporated, and the residue distilled. Methoxytetralone, b. p. 130—134°/0·6 mm., sufficiently pure for most purposes, was obtained in 85—90% yield.

3-*Keto*-7-*methoxy*-3 : 9 : 10 : 11-*tetrahydro*-1 : 2-cyclo*pentanophenanthrenes*-*B and* -*C* (V).—A mixture of powdered sodamide (5·7 g.), 6-methoxy-α-tetralone (25·5 g.), and dry ether (400 c.c.) was refluxed for 7 hours with stirring in a current of dry nitrogen, after which time only traces of ammonia were present. Acetyl*cyclo*pentene (16 g.; method of Robinson and Hawthorne, J., 1936, 763) was then added dropwise with stirring and ice-cooling, and the stirring continued for 6 hours at room temperature. Next day, dilute hydrochloric acid was added, and the crystalline product collected and well washed with water, alcohol, and ether. The crude product (15·0 g.) was crystallised from ethyl alcohol (500 c.c.). The main product (isomeride-A; Rapson

and Robinson, *loc. cit.*) separated in long needles (8·3 g.), m. p. 186—187°. Two further crystallisations raised the m. p. to 194—195°.

The mother-liquors from the first crystallisation of the crude product were concentrated to *ca.* 50 c.c. On keeping, a further small amount (0·5 g.) of isomeride-A crystallised; after this had been removed, a second substance (3·8 g.) was deposited in shining plates. The substance crystallised from ethyl alcohol in needles, rapidly changing to plates, m. p. 123—124° (Found : C, 80·6; H, 7·5; OMe, 11·6. $C_{18}H_{20}O_2$ requires C, 80·6; H, 7·5; OMe, 11·6%). The *substance* was much more readily soluble in most solvents than the isomeride-A.

The ethereal solution from the condensation was evaporated, and the residue dissolved in a small amount of ethyl alcohol. On keeping, the isomeride-A (1·0 g.) crystallised. The mother-liquors were diluted with water and the material recovered with the aid of ether was fractionated, yielding (i) methoxytetralone (13·0 g.), b. p. 130—150°/0·2 mm.; (ii) a yellow viscous oil (1·1 g.), b. p. 200—220°/0·2 mm., which partly crystallised in contact with ether. The crystalline material freed from oil was dissolved in hot aqueous acetic acid, from which it crystallised as a mixture of light needles (isomeride-A) and heavy, octahedral prisms. The latter were easily separated because of their greater density, which permitted the lighter needles to be swirled off. The residue (0·2 g.) crystallised from ethyl alcohol in square plates, m. p. 167—169° (mixed m. p. with isomeride-A, 154—156°) (Found : C, 80·5; H, 7·8%). The same *substance* was obtained in larger quantities by refluxing the reaction mixture for 4 hours after the addition of the acetyl*cyclo*pentene. In this case, isomeride-B was present only in small quantities. The mother-liquors from the recrystallisation of the crude product (A), on standing, slowly deposited isomeride-C in a fairly pure condition. The absorption of the isomerides-A, -B and -C was examined in alcoholic solution (fig.).



Ketomethoxytetrahydrocyclopentanophenanthrenes.

3-*Keto*-7-*methoxy*-3 : 4 : 9 : 10 : 11 : 12-*hexahydro*-1 : 2-cyclo*pentanophenanthrene*-α (VI).—Ketomethoxytetrahydro*cyclo*pentanophenanthrene-A (1 g.) was shaken with ethyl acetate and palladised strontium carbonate in an atmosphere of hydrogen at normal pressure. Absorption of *ca.* 1·4 mols. of hydrogen occurred slowly. The catalyst and solvent were removed, and the ketonic portion isolated as the sparingly soluble semicarbazone (0·35 g.). This was hydrolysed with boiling dilute hydrochloric acid, and the *product* crystallised from ethyl alcohol, separating in needles, m. p. 147—148° (Found : C, 80·3; H, 8·5. $C_{18}H_{22}O_2$ requires C, 80·0; H, 8·2%).

3-*Keto*-7-*methoxy*-2-*methyl*-3 : 4 : 9 : 10 : 11 : 12-*hexahydro*-1 : 2-cyclo*pentanophenanthrene*-α (VII).—Methyl iodide (7 c.c.) was added to the above isomeride-α (1·4 g.), previously dissolved in a solution of potassium (1·1 g.) in *tert.*-butyl alcohol (21 g.) and ether (21 c.c.), and the mixture was then refluxed for 1 hour. Water was added and the product, isolated by means of ether, was taken up in a little ethyl alcohol, from which it crystallised on keeping (1·05 g.). The *substance* separated from methyl alcohol in prisms, m. p. 68—69° (Found : C, 80·4; H, 8·7. $C_{19}H_{24}O_2$ requires C, 80·3; H, 8·5%). In contrast to its isomeride-β (*q.v.*), it exhibited very weak ketonic properties, the semicarbazone being particularly difficult to form.

3-*Keto*-7-*methoxy*-3 : 4 : 9 : 10 : 11 : 12-*hexahydro*-1 : 2-cyclo*pentanophenanthrene*-β (VI).—Ketomethoxytetrahydro*cyclo*pentanophenanthrene-B (1 g.) was catalytically reduced in dry ethyl acetate solution, the absorption of hydrogen being rapid and only slightly more than the theoretical for 1 mol. of hydrogen. On removal of the ethyl acetate, the *product* crystallised; recrystallised from ethyl alcohol, it separated in long needles, m. p. 118—118·5° (Found : C, 79·8; H, 8·1; OMe, 11·5. $C_{18}H_{22}O_2$ requires C, 80·0; H, 8·2; OMe, 11·5%). The *dinitrophenylhydrazone* separated from ethyl alcohol–pyridine in small, orange needles, m. p. 193—194° (Found : C, 64·1; H, 5·9. $C_{24}H_{26}O_5N_4$ requires C, 64·0; H, 5·8%).

3-*Keto*-7-*methoxy*-2-*methyl*-3 : 4 : 9 : 10 : 11 : 12-*hexahydro*-1 : 2-cyclo*pentanophenanthrene*-β (VII).—The above isomeride-β (1 g.) was dissolved in a solution of potassium (0·8 g.) in *tert.*-butyl alcohol (15 g.) and ether (20 c.c.), and the resultant pale yellow solution refluxed with methyl iodide (5 c.c.) for 1 hour. Water was then added, and the ethereal layer evaporated to dryness. The residue was dissolved in ethyl alcohol, but no crystallisation occurred; the ketonic product was therefore isolated as the semicarbazone (0·7 g.), which was hydrolysed with

boiling dilute hydrochloric acid. The oily product was isolated with the help of ether and was dissolved in a few drops of ethyl alcohol, from which it crystallised on keeping in the ice-chest in shapely prisms (0·5 g.), which were recrystallised from light petroleum (b. p. 40—60°) and finally from methyl alcohol, separating in prisms, m. p. 75—76° (Found: C, 80·2; H, 8·6; OMe, 10·9, 10·7; *C*-Me, 6·4, 5·8. $C_{19}H_{24}O_2$ requires C, 80·3; H, 8·5; OMe, 10·9; *C*-Me, 5·3%. Control determinations on the corresponding unmethylated ketone gave *C*-Me, 1·4, 0·9%). The m. p. was lowered more than 20° by addition of the methylated isomeride-α. The *dinitrophenylhydrazone* crystallised from ethyl alcohol–pyridine in small, orange needles, m. p. 171—172°, depressed to 167—169° by admixture with the unmethylated dinitrophenylhydrazone (Found: C, 64·6; H, 6·1. $C_{25}H_{28}O_5N_4$ requires C, 64·6; H, 6·0%). The semicarbazone separated from aqueous pyridine in small prisms, m. p. 226—227°.

*7-Methoxy-2-methyl-3 : 4 : 9 : 10 : 11 : 12-hexahydro-1 : 2-*cyclo*pentanophenanthrene* (VIII).—The saturated ketone-β (3·7 g.) was methylated as already described, and the crude semicarbazone (3·3 g.) recrystallised from aqueous pyridine, yielding practically pure semicarbazone (2·4 g.), m. p. 223—224°. Without further purification this was heated with a solution of sodium (1·6 g.) in ethyl alcohol (20 c.c.) at 180° for 20 hours. No demethylation occurred (cf. Cohen, Cook, Hewett, and Girard, J., 1934, 864). After dilution with water, the product (2·0 g.) was isolated by means of ether, and distilled from sodium. The colourless viscous distillate (1·2 g.; b. p. 183°/2 mm.) crystallised; recrystallised from methyl alcohol, it formed fine needles, m. p. 55—55·5° [Found: C, 84·0; H, 9·9; OMe, 11·6, 11·3; *C*-Me, 3·2, 2·9; *M* (*X*-ray), 275 (limits 268—280). $C_{19}H_{26}O$ requires C, 84·4; H, 9·6; OMe, 11·5; *C*-Me, 5·6%; *M*, 270].

The following *X*-ray data are due to Miss D. M. Crowfoot:

$$a = 18{\cdot}0\ (\alpha),\ b = 7{\cdot}16\ (\beta),\ c = 25{\cdot}0\ (\gamma);\ n = 8;\ \rho = 1{\cdot}13 \pm 0{\cdot}03.$$

For comparison the cell dimensions of the stereoisomeric optically active compound obtained by reduction of oestrone methyl ether are:

$$a = 11{\cdot}4,\ b = 7{\cdot}15,\ c = 19{\cdot}25;\ n = 4.\quad \text{Space group } P2_12_12_1.$$

No great accuracy is claimed for the latter values. We are greatly indebted to Professor J. W. Cook for the provision of a specimen of methoxymethylhexahydro*cyclo*pentanophenanthrene prepared by him from oestrone.

*Dehydrogenation of Methoxymethylhexahydro*cyclo*pentanophenanthrene.*—The substance (1·6 g.) was heated in a sealed tube with selenium (3 g.) at 300—320° for 5 days, the tube being opened and resealed from time to time. The dark product was taken up in ether, and the residue finely ground and extracted (Soxhlet) with benzene. The combined benzene and ethereal extracts were evaporated to dryness, and the residue distilled. The colourless product (1·0 g.; b. p. 150—170°/0·1 mm.) partly crystallised on cooling. Analysis suggested that the substance was *cyclo*pentenophenanthrene contaminated with a little 7-methoxy*cyclo*pentenophenanthrene. It was therefore heated with acetic acid (10 c.c.) and hydriodic acid (10 c.c.) for 4 hours, diluted with water, recovered with the use of ether, and distilled from sodium. The colourless distillate (0·7 g.; b. p. 165—172°/1 mm.) crystallised on cooling and after recrystallisation from methyl alcohol the product (0·15 g.) was converted into the *s*-trinitrobenzene complex. This was thrice crystallised from methyl alcohol (yellow needles) and had m. p. 164·5—165°, not depressed by admixture with an authentic specimen of *cyclo*pentenophenanthrene *s*-trinitrobenzene complex (Found: C, 64·0; H, 4·1. Calc. for $C_{23}H_{17}O_6N_3$: C, 64·0; H, 4·0%). The hydrocarbon, regenerated from the complex by treatment with alcoholic stannous chloride, crystallised from ethyl alcohol in needles, m. p. 135°, alone or mixed with pure *cyclo*pentenophenanthrene prepared by the method of Cook and Hewett (J., 1933, 1098). The removal of a methoxyl group situated in the benzene nucleus in this reaction is of considerable interest and may prove within limits to be a general reaction. The reducing agent is considered to be hydrogen selenide and the essentials would appear to be selenium and a hydroaromatic substance at an elevated temperature. Using tetralin as a source of hydrogen, it has already been found that selenium acts partly at least as a catalyst and some difficult reductions have been effected. It is hoped that an account of the scope of this method may shortly be submitted.

*7-Hydroxy-3-keto-3 : 9 : 10 : 11-tetrahydro-1 : 2-*cyclo*pentanophenanthrene.*—3-Keto-7-ethoxy-3 : 9 : 10 : 11-tetrahydro-1 : 2-*cyclo*pentanophenanthrene (1·0 g.; Hawthorne and Robinson, *loc. cit.*) was refluxed with aluminium bromide (3·0 g.) in purified benzene (50 c.c.) for 4 hours. The resulting liquid complex was decomposed with dilute hydrochloric acid and the almost colourless solid (0·5 g.) was collected and crystallised from ethyl alcohol, separating in fine needles, m. p. 249° (Found: C, 80·5; H, 7·3. $C_{17}H_{16}O_2$ requires C, 80·3; H, 7·1%). It gave

no ferric reaction, but was soluble in hot dilute sodium hydroxide solution, from which the sparingly soluble yellow sodium salt crystallised in needles on cooling.

*7-Hydroxy-3-keto-3 : 4 : 9 : 10 : 11 : 12-hexahydro-1 : 2-*cyclo*pentanophenanthrene.*—The foregoing substance (0·3 g.) was catalytically reduced in ethyl-alcoholic solution at normal pressure, palladised strontium carbonate being used. Hydrogen in slight excess of 1 mol. was rapidly absorbed. The catalyst and solvent were removed, the residue dissolved in dilute aqueous sodium hydroxide, and the solution boiled with charcoal for 1 hour. The cold filtered solution was acidified with acetic acid, and the white solid collected and crystallised from ethyl alcohol, forming small needles, m. p. 187—189° (decomp.) (Found : C, 79·8; H, 7·8. $C_{17}H_{20}O_2$ requires C, 79·7; H. 7·8%).

3-Keto-1-furyl-2-methyl-1 : 2 : 3 : 9 : 10 : 11-hexahydrophenanthrene.—(A) Sodio-α-tetralone was prepared by refluxing a mixture of tetralone (10 g.), sodamide (2·8 g.), and dry ether (200 c.c.) with stirring in an atmosphere of dry nitrogen for 5 hours. β-Furyl*iso*propenyl methyl ketone (10·3 g.; b. p. 117—120°/10 mm.) in ether (20 c.c.) was then added dropwise at – 10° to – 12° with stirring, which was continued for 5 hours at room temperature. After keeping overnight, the crystalline product was collected and recrystallised from ethyl alcohol, from which it separated in long, colourless prisms (1·2 g.), m. p. 137·5—138° (Found : C, 82·1; H, 6·7. $C_{19}H_{18}O_2$ requires C, 82·0; H, 6·5%). A further quantity (2·5 g.) of the same substance was obtained by concentration of the ethereal layer from the initial condensation.

(B) α-Tetralone (10 g.) in ether (200 c.c.) was added to a solution of potassium (2·8 g.) in *tert.*-butyl alcohol (33 g.), and the clear red solution cooled to – 15°. Furyl*iso*propenyl methyl ketone (10·3 g.) in ether (20 c.c.) was then introduced at such a rate that the temperature did not rise above –10°. Towards the end of the addition, crystals appeared around the neck of the flask. Stirring was continued at room temperature for 3 hours; water was then added, the product extracted with ether, the extract washed with dilute aqueous sodium hydroxide and evaporated, and the residual dark oil seeded. Crystallisation slowly ensued, yielding the same substance (1·3 g.) as in (A) but in much inferior yield.

3-Hydroxy-1-furyl-2-methyl-1 : 2 : 3 : 4 : 9 : 10 : 11 : 12-octahydrophenanthrene.—The foregoing substance (3·0 g.) in methyl alcohol (100 c.c.) was shaken with palladised strontium carbonate (2 g. of 2%) at 3 atms. pressure of hydrogen for 15 hours. The residue crystallised after removal of the catalyst and solvent; recrystallised from light petroleum (b. p. 60—80°), it separated in flocculent needles (2·1 g.). A portion recrystallised from aqueous ethyl alcohol formed long, fine needles, m. p. 140—140·5° (Found : C, 80·5; H, 7·9. $C_{19}H_{22}O_2$ requires C, 80·8; H, 7·8%).

An attempt to open the furyl ring was made in that the finely powdered substance was shaken with an excess of bromine water in the cold for 24 hours. The heavily brominated product was acidic but amorphous and all attempts to remove the bromine either by catalytic reduction or with sodium and ethyl alcohol were unsuccessful.

3-Keto-1-methyl-1 : 2 : 3 : 9 : 10 : 11-hexahydrophenanthrene.—(A) Sodio-α-tetralone was prepared as previously described from α-tetralone (10 g.), sodamide (2·8 g.), and ether (200 c.c.). The flask was then cooled in a freezing mixture, and ethyl ethylideneacetoacetate (10·8 g.; b. p. 97—99°/14 mm.) in ether (50 c.c.) added dropwise with stirring. Stirring was continued for 3 hours at 0°, and the mixture left overnight. It was then decomposed with ice and dilute hydrochloric acid, the ethereal layer dried (sodium sulphate) and evaporated, and the residue fractionated under reduced pressure. After a small low-boiling fraction (1·2 g.) up to 115°/15 mm., tetralone (5·6 g.) was collected at 94—140°/1 mm., and then a third fraction (5·2 g.; b. p. 160—190°/1 mm., practically all 181—190°), which crystallised in the receiver. It was recrystallised from light petroleum (b. p. 60—80°) or aqueous ethyl alcohol and obtained in plates, m. p. 119—120° (Found : C, 84·7; H, 7·6. $C_{15}H_{16}O$ requires C, 84·9; H, 7·5%). The substance gave no coloration with alcoholic ferric chloride.

(B) The condensation was also effected with potassium *tert.*-butoxide, but as in the previous case the yield was much inferior to that obtained with sodamide.

The p-*Phenylphenacyl Ester of γ-Carboxypropylideneacetone.*—Ethyl γ-carbethoxypropylideneacetoacetate (38 g.; Peak, Robinson, and Walker, J., 1936, 754) was boiled with 10% hydrochloric acid (100 c.c.) until it passed completely into solution (2 hours). During the hydrolysis a considerable volume of carbon dioxide was evolved. The hydrochloric acid was then removed under reduced pressure; the residue (17·5 g.) distilled as a colourless liquid, b. p. 160—166°/13 mm. This acid rapidly decolorised aqueous alkaline permanganate solution. The p-*phenylphenacyl* ester, prepared in the usual manner, separated from ethyl alcohol in needles, m. p. 93—94° (Found : C, 74·8; H, 6·1. $C_{21}H_{20}O$ requires C, 75·0; H, 6·0%).

Condensation of α-Tetralone and Ethyl γ-Carbethoxypropylideneacetoacetate.—Sodio-α-tetralone

prepared from tetralone (10 g.), sodamide (2·8 g.), and ether (200 c.c.) was cooled in a freezing mixture, and ethyl γ-carbethoxypropylideneacetoacetate (16·7 g.) in ether (50 c.c.) added dropwise with stirring. The reaction mixture was stirred for 4 hours at 0° and left overnight. It was decomposed with ice and dilute hydrochloric acid, and the ethereal layer washed with dilute aqueous sodium carbonate, which removed most of the colour. The dried ethereal solution was evaporated and on fractionation there were obtained: (i) b. p. up to 110°/14 mm. (2 g.), a colourless liquid with a red ferric reaction and an odour similar to that of ethyl acetoacetate; (ii) b. p. 120—140°/14 mm. (5·5 g.), unchanged tetralone; (iii) b. p. 190—200°/0·8 mm. (6·65 g.). The last fraction was a pale yellow, fairly mobile liquid giving a strong violet ferric reaction and a positive test for an aromatic nucleus (nitration and eventual formation of an azo-compound). It was evidently a mixture, since extraction of its ethereal solution with 10% aqueous sodium hydroxide removed an acidic substance (see below) and the material on recovery by distillation then exhibited no ferric reaction. Analytical results did not tally with the expected values (*Found*: C, 69·5, 69·5; H, 7·3, 7·4; OEt, 20·0. $C_{19}H_{22}O_3$ *requires* C, 72·2; H, 7·6; OEt, 15·1%). On treatment with Brady's reagent, however, the substance slowly yielded a solid derivative, which was crystallised repeatedly from ethyl alcohol and from acetic acid, separating in red prisms, m. p. 183—184° (Found: C, 60·5; H, 5·0; N, 11·9; OEt, 8·5. $C_{25}H_{28}O_7N_4$ requires C, 60·7; H, 5·3; N, 11·4; OEt, 9·1%). It may be suggested that this substance is an azo-derivative formed by addition of dinitrophenylhydrazine to the double bond of the anticipated product and oxidation.

The acidic *substance* obtained by acidification of the sodium hydroxide washings was purified by trituration with ether, which removed all the colour, and by crystallisation from boiling water, from which it separated in colourless needles, m. p. 202·5—203·5° after sintering at 196° (Found: C, 57·5; H, 5·0; OEt, 15·0. $C_{14}H_{14}O_7$ requires C, 57·1; H, 4·8; OEt, 15·4%). The substance was easily soluble in dilute sodium carbonate solution and was reprecipitated by hydrochloric acid. It gave an intense red ferric reaction and was insoluble in non-hydroxylic solvents. The constitution of this acid has not been determined, but it appears to be ketonic. The *dinitrophenylhydrazone* crystallised from ethyl alcohol in orange needles, m. p. 205—207° (Found: C, 50·2; H, 4·8; N, 11·1. $C_{20}H_{18}O_{10}N_4,C_2H_6O$ requires C, 50·6; H, 4·6; N, 10·8%). The substance was easily soluble in sodium hydroxide and gave no ferric reaction.

Attempted Condensation of 6-Methoxy-α-tetralone and Ethyl γ-Carbethoxypropylideneacetoacetate.—The sodio-derivative of the ketone (7·3 g.) was made as usual in ether (140 c.c.), and the unsaturated ester (10 g.) in ether (30 c.c.) then added. After standing overnight, the product was worked up as before. Methoxytetralone (5·4 g.) was recovered, and a small fraction (1·7 g.; b. p. 210—214°/0·7 mm.) obtained as a viscous yellow oil. No crystalline derivatives could be obtained and in view of the unfavourable yield the condensation was not further investigated.

Ethyl γ-Phenylpropylideneacetoacetate.—A mixture of ethyl acetoacetate (10 g.), β-phenylpropaldehyde (10·3 g.), and acetic anhydride (15 g.) was heated for 24 hours at 100°. The acetic anhydride was then removed under reduced pressure, and the residue fractionated. After a small amount of unchanged material, the main fraction was collected at 145—160°/0·35 mm. (16·5 g.). After redistillation (b. p. 140—143°/0·1 mm.), it had $n_D^{15°}$ 1·5241 and gave no ferric reaction (Found: C, 72·7; H, 7·0. $C_{15}H_{18}O_3$ requires C, 73·2; H, 7·3%).

Attempted Condensation of the Foregoing with α-Tetralone.—Sodio-α-tetralone was prepared as previously from tetralone (3·7 g.) in ether (100 c.c.). After cooling to −15°, ethyl γ-phenylpropylideneacetoacetate (6·4 g.) in ether (20 c.c.) was added dropwise, and the mixture stirred for 4 hours and left overnight. After decomposition with dilute hydrochloric acid, there remained a small amount of insoluble solid, which was collected. It crystallised from ethyl alcohol in colourless shining plates, m. p. 130·5—131° (Found: C, 88·6; H, 7·5%). Although this was undoubtedly a pure substance, the analysis does not confirm our anticipations. The residual, ether-soluble product yielded on fractionation unchanged tetralone (2·6 g.) and a viscous yellow oil (2·8 g.; b. p. 205—245°/1 mm., decomp.). The material was obviously a mixture and could not be induced to yield any crystalline derivative.

Ethyl 2-Methylcyclopentanone-3-carboxylate.—The method of Haworth and Perkin (J., 1908, 93, 581) has been slightly modified. (i) Ethyl cyano-2-methylsuccinate was obtained in 70% yield exactly as described by Bone and Sprankling (J., 1899, 75, 853). The observed b. p. was, however, 150—153°/17 mm., not 160—165°/17 mm. as stated by these authors.

(ii) The ester (112 g.) was added to a cold solution of sodium (12·1 g.) in absolute alcohol (200 c.c.), and ethyl β-chloropropionate (71·8 g.) added dropwise, the temperature being kept below 25°. Next day, the mixture was heated for 1 hour on the steam-bath. Worked up in the usual way, it yielded 148 g. (90%) of the pure product, b. p. 160—165°/3 mm. If ethyl

malonate is substituted for ethyl cyanoacetate in this series of processes, a very poor yield is obtained at this stage.

(iii) Ethyl 3-cyanopentane-2 : 3 : 5-tricarboxylate (148 g.) was refluxed with concentrated hydrochloric acid (3 vols.) and the alcohol formed was distilled through a refluxing fractionating column until solution was complete. The solution was concentrated by distillation until ammonium chloride began to separate and then evaporated to dryness on the steam-bath. The solid cake of ammonium chloride and pentane-2 : 3 : 5-tricarboxylic acid was heated with absolute alcohol (300 c.c.), carbon tetrachloride (240 g.), and concentrated sulphuric acid (30 c.c.) under an efficient fractionating column, through which the azeotropic mixture of alcohol, carbon tetrachloride, and water was slowly distilled. A mixture of equal volumes of alcohol and carbon tetrachloride was added at the same rate as the distillate was removed. The process was continued until the distillate no longer clouded on cooling (*ca.* 30 hours with a very slow rate of distillation). The product, recovered in the usual way, distilled at 146—149°/3 mm. (yield, 81%, over-all from the cyano-ester).

(iv) The foregoing ester (110 g.) was added slowly to dry, powdered sodium ethoxide (30 g.) in dry ether (200 c.c.). The mixture became warm and the sodium ethoxide passed into solution. After refluxing for 2 hours, dilute hydrochloric acid was added, and the ethereal layer washed with dilute aqueous sodium carbonate, which removed most of the colour. (These washings were acidified with hydrochloric acid and refluxed for 4 hours. The cold solution was then extracted with the ether to be used in the first extractions of the next stage.) After the ethereal solution had been dried (sodium sulphate), the ether was evaporated, and the residue distilled, b. p. 143—148°/6 mm. (71 g. or 77%).

(v) 2-Methyl*cyclo*pentanone-3-carboxylic acid was obtained by hydrolysis of the foregoing substance in the known manner, except that the alcohol resulting from the hydrolysis was removed by slow distillation through a fractionating column. The white crystalline acid thus obtained had b. p. 147—149°/3 mm. (97% yield).

The acid (40·2 g.) was esterified by the above-described method. The ester had b. p. 116—118°/16 mm. (40·0 g. or 83%).

Attempted condensations of this ester with diethylaminobutanone methiodide by means of dry sodium ethoxide in ether at −10° or of potassium *tert.*-butoxide in ether and *tert.*-butyl alcohol gave negative results in both cases. Most of the material was converted into resinous high-boiling substances.

Diethylamide of 2-*Methyl*cyclo*pentanone*-3-*carboxylic Acid.*—The acid (10·2 g.) was dissolved in ether (40 c.c.) and dry pyridine (5·7 g.), and thionyl chloride (8·6 g.) added dropwise with ice-cooling. Pyridine hydrochloride first separated crystalline but later became dark and oily. After keeping overnight, the ether was decanted, and a solution of diethylamine (12 g.; 2 mols.) in ether (20 c.c.) added slowly. After refluxing for 1 hour, the mixture was poured on the pyridine hydrochloride residue, and the whole well shaken and refluxed for a short time. Water was then added, and the ethereal layer dried. There was obtained by distillation a fraction (4·5 g.), b. p. 132—135°/0·5 mm., and on redistillation 117—119°/0·1 mm. (Found: N, 6·8. $C_{11}H_{19}O_2N$ requires N, 7·1%). The *dinitrophenylhydrazone* crystallised from ethyl alcohol in glistening orange plates, m. p. 199—199·5° (Found: C, 54·5; H, 6·2; N, 18·5. $C_{17}H_{23}O_5N_5$ requires C, 54·1; H, 6·1; N, 18·6%).

6-*Methylheptan*-2-*ol.*—6-Methylheptan-2-one (101 g.), obtained in almost theoretical yield by the catalytic reduction of methylheptenone, was heated under an efficient fractionating column with aluminium *iso*propoxide (53 g.; 1/3 mol.) and dry *iso*propyl alcohol (200 c.c.). Acetone, which was freely evolved, was gradually distilled and replaced by fresh *iso*propyl alcohol until acetone could not be detected in the distillate. The excess of *iso*propyl alcohol was evaporated as completely as possible, and the residue decomposed with dilute hydrochloric acid and extracted with ether. The extract was dried and evaporated, and the residue distilled, giving pure methylheptanol (95·5 g.), b. p. 78—81°/16 mm., $n_D^{19°}$ 1·4273.

2-*Chloro*-6-*methylheptane.*—A mixture of methylheptanol (20 g.), dimethylaniline (18·6 g.), and dry chloroform (40 c.c.) was cooled in ice, and thionyl chloride (18·3 g.) in chloroform (10 c.c.) added dropwise. The solution was refluxed for 2 hours, water added, and the chloroform layer dried. The chloroform was distilled through a fractionating column, and the residue distilled. The fraction, b. p. 57—63°/15 mm. (16·7 g.), was freed from unchanged alcohol by cooling to 0° and shaking with cold concentrated sulphuric acid. After washing with water, it was redistilled, yielding the pure product, b. p. 74—75°/35 mm., $n_D^{15°}$ 1·4260 (Found: C, 64·4; H, 11·4; Cl, 24·0. $C_8H_{17}Cl$ requires C, 64·7; H, 11·4; Cl, 23·9%). A Grignard solution was prepared from the *chloride* (10·2 g.) and activated magnesium (1·7 g.) in ether (100 c.c.), but only with

great difficulty. The solution had to be heated continuously and a considerable quantity of magnesium chloride was produced. The cold solution was added slowly to ethyl β-formylpropionate (8·0 g.) in ether (10 c.c.) at 0°. A little complex was precipitated. Worked up in the usual way, the product yielded, besides low-boiling fractions (4·1 g.), a small fraction (2·7 g.), b. p. 117—120°/1 mm. This, however, was not lactonic in nature and because of the poor yield was not further investigated. An estimation of the percentage of organomagnesium compound formed (carbon dioxide on the cold solution and titration of the acid formed) gave as a maximum value, 41%.

2-Iodo-6-methylheptane.—Methylheptanol (20 g.) was mixed with red phosphorus (2 g.), and iodine (20 g.) added in portions with shaking. After standing overnight at room temperature, the mixture was heated at 100° for 2 hours. The product was then distilled (b. p. 72—78°/14 mm.), taken up in chloroform (50 c.c.), the free iodine removed by washing with aqueous sodium thiosulphate, and the colourless solution dried. It was then cooled to − 10°, shaken with concentrated sulphuric acid (½ vol.) also cooled to − 10°, washed with water, dried, and evaporated. The residue distilled at 83°/14 mm. (31 g.) (Found: C, 41·0; H, 7·5. $C_8H_{17}I$ requires C, 40·0; H, 7·1%). It was a heavy, colourless, mobile liquid, $n_D^{17°}$ 1·4870.

Reaction of magnesium (2 g.) in ether (10 c.c.) was initiated with methyl iodide (0·5 g.), and a solution of the iodide (20 g.) in ether (75 c.c.) added dropwise. The reaction proceeded smoothly and was completed by refluxing for 15 minutes; a considerable quantity of magnesium, however, remained undissolved. The solution was added to ethyl β-formylpropionate (10 g.) in ether (75 c.c.) at 0°. Only a small amount of complex was precipitated. After shaking for 15 minutes, the product was worked up as usual. There were obtained: (i) unchanged iodide (5 g.); (ii) b. p. 103—108°/3 mm. (3·2 g.), a colourless liquid insoluble in boiling caustic soda solution and immiscible with alcohol and therefore probably 2 : 6 : 7 : 11-tetramethyldodecane; (iii) b. p. 134—144°/3 mm. (1 g.), not a lactone and therefore not further investigated; (iv) a very high-boiling residue.

Note.—No success was achieved in attempts to introduce the residues of ethyl α-bromopropionate and ethyl β-chloropropionate into ethyl acetoacetate. In whichever order the condensations were carried out, the second did not take place.

Δ^1-Dihydrocitronellylideneacetic Acid.—Dihydrocitronellal (26 g.; b. p. 76—79°/12 mm.; $n_D^{17°}$ 1·4281) was heated with malonic acid (18 g.), pyridine (40 c.c.), and piperidine (1 c.c.) at 100° for 6 hours. During the first hour there was a copious evolution of carbon dioxide. The mixture was then poured into aqueous sodium hydroxide (100 c.c. of 10%), extracted with ether, acidified, and the oil extracted with ether. The product had b. p. 158—161°/12 mm., $n_D^{14°}$ 1·4590 (25·6 g.).

Prolonged treatment with boiling 62% sulphuric acid failed to effect any lactonisation (cf. Fittig, *Annalen*, 1894, **283**, 51).

Δ^8-Dihydrocitronellylideneacetic Acid.—Citronellylideneacetic acid (13 g.; Rupe, Pfeiffer, and Splittgerber, *Ber.*, 1907, **40**, 2813) was dissolved in aqueous sodium hydroxide (100 c.c. of 1%) and heated at 100° for 12 hours with sodium amalgam (500 g. of 3%). During the latter part of the reduction, the mixture was vigorously stirred. The alkaline layer was acidified and extracted with ether, and the extract evaporated. The product (11 g.), b. p. 162—166°/12 mm., $n_D^{15°}$ 1·4668, was only partly reduced (Found: C, 73·0; H, 10·6. $C_{12}H_{22}O_2$ requires C, 72·7; H, 11·1%. $C_{12}H_{20}O_2$ requires C, 73·5; H, 10·2%).

On treatment with concentrated sulphuric acid at 80° (cf. Shukow and Schestakow, *Chem. Zentr.*, 1908, II, 1414) this material was completely polymerised. No trace of lactone could be isolated.

Ethyl Δ^1-Dihydrocitronellylideneacetate and its Condensation with Ethyl Oxalate.—Dihydrocitronellylideneacetic acid (37 g.) was refluxed for 10 hours with ethyl alcohol (150 c.c.) and concentrated sulphuric acid (10 c.c.). The *ester*, isolated in the usual way, distilled at 128—131°/10 mm. (36 g.) (Found: C, 74·3; H, 11·5. $C_{14}H_{26}O_2$ requires C, 74·3; H, 11·5%).

Powdered potassium (3·0 g.) was added to ethyl oxalate (10·7 g.) in benzene (100 c.c.). The above ester (16·5 g.) was then added slowly. A moderately vigorous reaction soon set in, the benzene finally boiling and the solution becoming deep red. Next day the mixture was decomposed with dilute acetic acid, and the benzene layer dried and evaporated. The residue, which gave a deep red ferric reaction, could not be distilled even at 0·006 mm. without decomposition. The crude material (11·0 g.) was therefore catalytically reduced in alcoholic solution, *ca.* two-thirds of the theoretical volume of hydrogen being absorbed. Decomposition still occurred on attempted distillation at 0·006 mm.; the vacuum falling to 1 mm. At this pressure there was obtained a fraction (3 g.), b. p. 150—160°/1 mm., redistilling

at 131—136°/0·4 mm. (Found: C, 68·1; H, 10·8. $C_{17}H_{32}O_4$ requires C, 68·0; H, 10·7%). Evidently therefore carbon monoxide had been evolved during distillation.

Attempted Synthesis of β-nor*Dihydrocitronelloylpropionic Acid*.—(i) *Dihydrocitronellic acid.* Dihydrocitronellal (76·5 g.) was mixed with pure acetic acid (200 g.), and a solution of chromic acid (34 g.) in water (25 c.c.) added dropwise so that the temperature remained at *ca.* 50°. After standing for 12 hours, water and concentrated hydrochloric acid (100 c.c.) were added and the product was extracted with ether and distilled at 130—135°/10 mm. (63·0 g.).

(ii) *Ethyl dihydrocitronellate.* The acid (63 g.) was heated on the water-bath for 1 hour with thionyl chloride (50 g.). Excess of ethyl alcohol (50 c.c.) was added to the cold solution, and the mixture refluxed for 2 hours. It was then diluted with water, the oil extracted with ether, and the extract washed with dilute aqueous sodium carbonate and evaporated. The residue distilled at 98—100°/10 mm. (67·4 g.).

(iii) 8 : 8-*Diphenyl*-2 : 6-*dimethyl*-Δ^7-*octene.* Ethyl dihydrocitronellate (67 g.) was added dropwise to a Grignard solution prepared from bromobenzene (158 g.) and magnesium (24 g.) in ether (500 c.c.). There was a vigorous reaction, but no complex was precipitated. After refluxing for 2 hours, the ether was distilled, and the residue heated for 6 hours at 100°. It was then decomposed with dilute hydrochloric acid, and the resulting oil isolated with ether. On fractionation, after the distillation of a small amount of diphenyl, there was obtained a pale yellow oil, b. p. 150—157°/0·6 mm. (92 g.), immiscible with all hydroxylic solvents.

(iv) nor*Dihydrocitronellic acid.* The hydrocarbon (70 g.) was emulsified with acetic acid (400 c.c.) by stirring, and solid chromic acid (75 g.) added in small portions so that the temperature remained at 50—60°. When the solution had cooled, water and concentrated hydrochloric acid (225 c.c.) were added. An ethereal extract of the product was washed with water and evaporated, and acetic acid distilled through a short fractionating column. The residue was added to 10% aqueous sodium hydroxide (100 c.c.), and the benzophenone extracted with ether. The alkaline solution was acidified, and the product isolated by means of ether. On fractionation practically the whole distilled at 127—129°/10 mm. (22·8 g. or 60%) (Found: C, 68·3; H, 11·4. $C_9H_{18}O_2$ requires C, 68·3; H, 11·4%).

(v) *nor*Dihydrocitronellic acid (25·8 g.) was heated for 2 hours with thionyl chloride (26 c.c.). The excess of thionyl chloride was then removed under reduced pressure, and the residue distilled, yielding *nor*dihydrocitronelloyl chloride (26·5 g.), b. p. 71—71·5°/8 mm.

Sodium (3·5 g.) was powdered under toluene and washed with ether, and ether (180 c.c.) added. Ethyl acetosuccinate (32·5 g.) was then added, and the vigorous reaction completed by heating on the steam-bath for 1 hour. The chloride (26·5 g.) in ether (30 c.c.) was added dropwise at 0° to the clear solution of ethyl sodioacetosuccinate. Gelatinous sodium chloride was precipitated and after 12 hours the reaction was completed by refluxing for 1 hour. Water was added, and the ethereal layer washed with dilute aqueous sodium carbonate (no unchanged acid on acidification). The ether was evaporated, and the residue stirred vigorously for 24 hours with 4·5% aqueous potassium hydroxide solution (1 l.). The small amount of unhydrolysed material was extracted with ether, and the alkaline layer acidified with sulphuric acid and saturated with ammonium sulphate. The liberated oil was extracted ten times with ether, the ether removed, and the residue heated at 140° for 2 hours. 10% Sodium hydroxide solution (300 c.c.) was then added, and the solution refluxed for 5 hours. After acidification the liberated oil was isolated with ether. On fractionation of the product, *nor*dihydrocitronellic acid (22·0 g.) was recovered, there being no significant residue. A repetition of the experiment using a shorter period of hydrolysis gave the same result.

When a specimen of acid which undoubtedly contained some dihydrocitronellic acid was usede a small amount of a keto-acid was obtained, b. p. 175—188°/5 mm. The *semicarbazon*, crystallised from ethyl alcohol in laminated plates, m. p. 156—157° (Found: C, 59·2; H, 9·2; N, 15·0. $C_{14}H_{27}O_3N_3$ requires C, 59·6; H, 9·5; N, 14·8%). Hence this substance is derived from dihydrocitronellic acid and not from the *nor*-compound.

Dyson Perrins Laboratory, Oxford University. [*Received, July* 30*th*, 1937.]

332. The Stereochemistry of Thianthren.

By GEORGE H. KEATS.

PREVIOUS authors have attempted the optical resolution of monosubstituted thianthrens, since it is known from dipole measurements that the thianthren molecule is non-planar. If the folded structure persists in solution, any monosubstituted thianthren derivative should be capable of existing in optically isomeric forms. Attempts to resolve 2-thianthrenyltrimethylammonium salts have proved unsuccessful, and a value calculated for the energy required for the transformation of thianthren from the folded to the planar state indicates a small degree of configurational stability.

IN view of the attempted optical resolution of thianthren derivatives (Bennett, Lesslie, and Turner, J., 1937, **444**), some relevant investigations carried out some time ago are recorded. 2-Aminothianthren was prepared, and its optical resolution attempted in order to see whether the folded structure of the thianthren molecule, deduced by studies of dipole moments, is sufficiently rigid to permit the existence of optical isomers.

By following Krishna's directions (J., 1923, **123**, 156) for the reduction of 2-nitrothianthren by zinc in 90% acetic acid, a product was obtained which had the same m. p. as that given for 2-aminothianthren; but this was actually the acetyl derivative, and hydrolysis afforded 2-aminothianthren, which proved to be so weak a base that salts with active acids could not be isolated (cf. Bennett, Lesslie, and Turner, *loc. cit.*, who obtained a coloured *d*-camphor-10-sulphonate). In view of these difficulties, *2-thianthrenyltrimethylammonium iodide* was made, and thence its well-defined salts with *d*-camphor-10-sulphonic acid, α-bromo-*d*-camphor-π-sulphonic acid, and *d*-diacetyltartaric acid. These were all repeatedly crystallised, but no evidence of optical resolution could be obtained.

It is therefore concluded that in solution the thianthren molecule oscillates so rapidly through a mean planar position that it virtually possesses a plane of symmetry. Sutton and Hampson (*Trans. Faraday Soc.*, 1935, **31**, 945), from measurements of the dipole moments of diphenyl sulphide and of thianthren, conclude that in these compounds the sulphur valency angle is approximately 110°. When the thianthren molecule assumes a planar configuration, the valency angles of both sulphur atoms become distorted to 120°, and the energy needed to effect this change can be estimated.

From the spectroscopic data for hydrogen sulphide (Penney and Sutherland, *Proc. Roy. Soc.*, 1936, *A*, **889**, 654), it is calculated that approximately 3600 cals. per mole are needed to increase the sulphur valency angle by 10°. If this value be taken to apply to the case of the sulphur bonds in thianthren, some 7000 cals. per mole would be required for the transformation of thianthren from the folded to the planar state. If this figure be accepted, it is clear that the facility with which the thianthren molecule may become planar is such that optical resolution would be impossible; for it is only when the heat of racemisation becomes more than some 20,000 cals. per mole that optical activity is observable.

EXPERIMENTAL.

2-Acetamidothianthren.—58 G. of 2-nitrothianthren were reduced by Krishna's method (*loc. cit.*). The product, after a preliminary crystallisation from xylene, crystallised from dilute alcohol in colourless plates, m. p. 186°; yield 36 g. (Found: C, 61·7; H, 4·3; N, 5·15. Calc. for $C_{14}H_{11}ONS_2$: C, 61·5; H, 4·0; N, 5·1%). The substance gives a deep purple solution in concentrated sulphuric acid.

2-Aminothianthren.—36 G. of the acetyl derivative were boiled under reflux with 700 c.c. of concentrated hydrochloric acid and 250 c.c. of alcohol for 8 hours. The product was cooled, and the resulting solid filtered off, digested with sodium hydroxide solution, collected, washed, and crystallised from dilute alcohol, from which it separated as colourless needles or plates, m. p. 160°; yield 29 g. (Found: C, 62·3; H, 4·0; N, 6·0. Calc. for $C_{12}H_9NS_2$: C, 62·4; H, 3·9; N, 6·0%). The base gives a red solution in concentrated sulphuric acid. It can be diazotised in hydrochloric acid, and the product couples with β-naphthol, giving a scarlet dye. Neither the hydrochloride nor the sulphate of 2-aminothianthren could be isolated from aqueous solutions.

2-Thianthrenyltrimethylammonium Iodide.—6 G. of 2-aminothianthren were shaken in 40 c.c. of water for 30 minutes with the addition of three successive 2-c.c. portions of methyl sulphate, the liquid being made alkaline before each addition. The mixture, containing a doughy lump of solid, was then heated on the water-bath for 15 minutes, made alkaline, and cooled. The oil which separated soon solidified, and was filtered off, washed, and dried. This crude material, consisting of partly and completely methylated amine, was not purified, but was heated with 30 c.c. of methyl iodide in a sealed tube at 100° for 24 hours. The methyl iodide was distilled from the dark product, and the residue refluxed with acetone. The mixture was cooled, and the solid filtered off and washed with acetone until it was only faintly cream-coloured. It crystallised from hot water in glistening, colourless plates, m. p. 190°; yield 6 g. (Found: C, 44·6; H, 4·2; N, 3·7; I, 31·4. $C_{15}H_{16}NIS_2$ requires C, 44·8; H, 4·0; N, 3·5; I, 31·6%).

The *iodide* is moderately soluble in hot ethyl and methyl alcohols, but practically insoluble in ether, chloroform, ethyl acetate, etc. On being shaken with silver chloride in water it is converted into the chloride, which is readily soluble in cold water, and crystallises from ethyl alcohol–ether in prisms, m. p. 181°. The nitrate, similarly prepared by means of silver nitrate, crystallises from water in prisms, m. p. 201°. Solutions of these salts in water give an immediate precipitation of the crystalline quaternary iodide on addition of a minute trace of alkali iodide.

Attempted Resolution of 2-Thianthrenyltrimethylammonium Salts.—(a) d-*Camphor-10-sulphonate.* 4·66 G. of *d*-camphor-10-sulphonic acid were treated in hot water with a slight excess of silver carbonate, and the filtered solution was heated for 1 hour on the water-bath with 8·04 g. of 2-thianthrenyltrimethylammonium iodide. The silver iodide was filtered off, and the aqueous solution on cooling deposited the *d*-camphor-10-sulphonate as colourless plates. It was crystallised from warm water. The molecular rotations of the successive crops of crystals (dried in a vacuum) remained steady at the value due to the *d*-camphor-10-sulphonate ion. The 1st, 3rd, 6th, and 7th crops had $[M]_{5461}^{16°}$ + 60·5°, + 61·5°, + 60·0°, and + 60·0° respectively (p = 0·8), and m. p. 140°. For the *d*-camphor-10-sulphonate ion under the same conditions, $[M]_{5461}^{16°}$ = + 57·5°.

(b) *α-Bromo-*d*-camphor-π-sulphonate.* This was similarly prepared from 4·02 g. of the quaternary iodide and 4·18 g. of the silver salt of the active acid. Crystallised from ethyl alcohol–ether, it separated in colourless needles. Three successive crystallisations gave crops having $[M]_{5461}^{16°}$ + 331° (0·1 g. in 23 c.c. H_2O + 2 c.c. EtOH), m. p. 224°. The α-bromo-*d*-camphor-π-sulphonate ion under the same conditions had $[M]_{5461}^{16°}$ + 332°.

(c) *Hydrogen* d-*diacetyltartrate.* 4·02 G. of 2-thianthrenyltrimethylammonium iodide were shaken with excess silver carbonate in 60 c.c. of water. After 2 hours the product was filtered, and the filtrate treated with 2·16 g. of *d*-diacetyltartaric anhydride. Air was passed through the solution to expel carbon dioxide, and when left in a vacuum desiccator overnight, the solution deposited crystals. Recrystallisation from methyl alcohol–ether afforded colourless prisms, giving an acid solution in water (Found: N, 2·75. Calc. for the acid salt: N, 2·75%). The 1st, 2nd, and 3rd crops had $[M]_{5461}^{16°}$ − 64·5°, − 65·5°, and − 65·5° respectively (p = 0·60), and m. p. 171° (decomp.). Under the same conditions, the hydrogen *d*-diacetyltartrate ion had $[M]_{5461}^{16°}$ − 63·5°.

To aqueous solutions of the active salts described in (a), (b), and (c), potassium iodide was added to precipitate the quaternary iodide. This was converted into the chloride by shaking with an aqueous suspension of silver chloride, and in every case the product was found to be optically inactive.

The author thanks Dr. W. H. Mills for useful discussions, and the Goldsmiths' Company for the award of a Senior Studentship.

UNIVERSITY CHEMICAL LABORATORY, CAMBRIDGE. [*Received, August 4th, 1937.*]

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333. *Reactions of αβ-Unsaturated Cyclic Aldehydes and Ketones. Part I. Their Conversion into Anilines.*

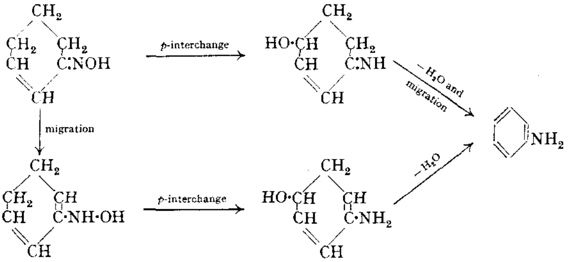
By R. G. COOKE and A. KILLEN MACBETH.

The product of the action of acetic anhydride on the oxime of *l*-4-*iso*propyl-Δ^2-*cyclo*hexen-1-one has been identified as 4-*iso*propylacetanilide, and the corresponding base has been isolated and identified by means of derivatives. The action is parallel to that described by Kotz and Grethe, who obtained aniline from Δ^2-*cyclo*hexenone-

oxime. Similar reactions have been found to occur with the oximes of piperitone and carvone, but these are much more stable and the yields of bases are much lower than in the preceding cases.

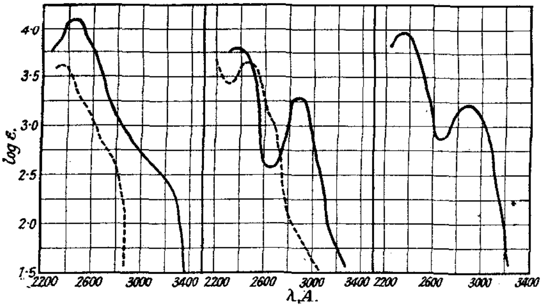
The absorption spectra of cumidine and thymylamine and their acetates have been examined and compared with those previously recorded for simple aromatic bases.

THE action of acetic anhydride on the oxime of 4-*iso*propyl-Δ^2-*cyclo*hexen-1-one gives a white crystalline product (Berry, Macbeth, and Swanson, this vol., p. 986) which has now been shown to be 4-*iso*propylacetanilide. Hydrolysis of the product, followed by steam-distillation, gives the corresponding base, cumidine (I), and the reaction thus finds a parallel in the work of Kotz and Grethe (*J. pr. Chem.*, 1909, **80**, 500), who isolated aniline when the oxime of Δ^2-*cyclo*hexenone was similarly treated. The mechanism of the reaction proposed by these workers involves *para*-interchange of a hydrogen atom and a hydroxyl group, followed by elimination of water, as formulated below :



The oximes of piperitone and carvone undergo a similar change, giving rise to the bases thymylamine (II) and carvacrylamine (III) respectively. The reaction with these sub-

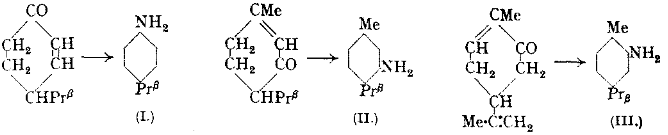
FIG. 1.



—— *Acetocumidide in* EtOH. —— *Thymylamine in* EtOH. —— *Cumidine in* EtOH.

---- *Acetothymylamide in* EtOH. ---- *Thymylamine in* HCl.

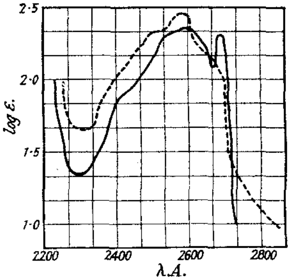
stances does not, however, proceed as readily as in the case of 4-*iso*propyl-Δ^2-*cyclo*hexen-1-one, and the yields of the bases are much lower.



(I.) (II.) (III.)

The absorption spectra of the pure bases were examined for comparison with those of the simple bases already recorded. The results are summarised in Table I and shown in Figs. 1 and 2. Cumidine and thymylamine show the two maxima characteristic of aromatic bases and of similar intensity (aniline : $\lambda_{max.}$ 2340 and 2845 A., log ε 4·06 and 3·24; *p*-toluidine : $\lambda_{max.}$ 2357 and 2905 A., log ε 4·01 and 3·3). The absorption of cumidine in 10% hydrochloric acid closely resembles that of *p*-toluidine in the same solvent, but one of the toluidine bands is represented by an inflexion only in the cumidine curve. In the case of acid solutions of thymylamine similar maxima are recorded, but the log ε values are higher.

FIG. 2.



—— p-*Toluidine in* HCl.
- - - - *Cumidine in* HCl.

The absorption of acetocumidide resembles that of aceto-*p*-toluidide ($\lambda_{max.}$ *ca.* 2450 A., log ε 4·28). In the aceto-*o*- and -*m*-toluidides the maxima are somewhat displaced towards shorter wave-lengths and the log ε values are lower (Morton and McGookin, J., 1934, 907) : and similar effects are observed in the case of acetothymylamide, in which no substituent is present in the *p*-position to the amino-group.

TABLE I.

	In alcohol.				In 10% hydrochloric acid.			
	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.
Cumidine	2348	3·99	2882	3·23	2585	2·43	*ca. 2660*	2·19
Thymylamine	2381	3·81	2865	3·27	2451	3·64	*ca. 2670*	3·08
Acetocumidide	2445	4·12						
Acetothymylamide	*ca.* 2320	3·63						
p-Toluidine	2357	4·01	2905	3·3	2599	2·36	2688	2·32

Italicised figures represent inflexions.

EXPERIMENTAL.

4-iso*Propylacetanilide.*—The oxime of 4-*iso*propyl-Δ^2-*cyclo*hexen-1-one (Berry, Macbeth, and Swanson, *loc. cit.*) was refluxed for 4 hours with acetic anhydride (10 parts) and anhydrous sodium acetate. After cooling, the mixture was poured into water, an ethereal extract of the product dried and evaporated, and the residual red-brown oil fractionated under reduced pressure. The high-boiling fraction, 195—210°/25 mm., soon solidified, and after drying on a porous tile yielded white needles, m. p. 103°, on recrystallisation from light petroleum (b. p. 60—80°). The product also separated in glistening leaves, m. p. 102°, from water. It was remarkably stable towards alkalis, and was precipitated unchanged from its solution in concentrated acids on dilution. It was, however, hydrolysed on refluxing with 70% sulphuric acid, and the solution yielded a scarlet dye with β-naphthol after diazotisation. After the addition of sodium hydroxide, a base was recovered from the hydrolysed solution by extraction with ether or by steam-distillation. The base was found to be cumidine (p-*iso*propylaniline) and the white crystalline material has been identified as acetocumidide (4-*iso*propylacetanilide) (Found : C, 74·8; H, 8·6; N, 7·9; *M*, 178. Calc. for $C_{11}H_{15}ON$: C, 74·6; H, 8·5; N, 7·9%; *M*, 177).

In further experiments the red-brown oil instead of being fractionated was forthwith sub-

jected to hydrolysis by 70% sulphuric acid (20 mins.' refluxing) and, after cooling, the undissolved oil was extracted with ether. The residue was steam-distilled after the addition of sodium hydroxide; cumidine extracted from the distillate, after drying over solid potassium hydroxide, distilled as a clear refractive oil, b. p. 220—222°/765 mm. It gave the *iso*nitrile reaction, formed azo-dyes after diazotisation, gave on treatment with acetyl chloride an acetyl derivative identical with that described above, yielded on benzoylation benzocumidide, which crystallised in white woolly needles, m. p. 160°, from alcohol (Found: C, 80·2; H, 7·3. Calc. for $C_{16}H_{17}ON$: C, 80·3; H, 7·1%), and on treatment with saturated aqueous oxalic acid gave an oxalate, m. p. 159° after recrystallisation from water (compare Constam and Goldschmidt, *Ber.*, 1888, **21**, 1157; Sachs and Weigert, *Ber.*, 1907, **40**, 4360).

Thymylamine from Piperitoneoxime.—Piperitone isolated from *E. Dives* by hot sodium sulphite solution (Read and Smith, *J. Soc. Chem. Ind.*, 1923, **42**, 339 T) had α_D − 12·5° after fractionation under reduced pressure. It was converted into the oxime by 5 hours' refluxing with alcoholic hydroxylamine hydrochloride (1 mol.) and anhydrous sodium acetate. After removal of the greater part of the alcohol the product was steam-distilled; the oxime which collected in the distillate had m.p. 117° after recrystallisation from alcohol (compare Simonsen, J., 1921, **119**, 1647).

The oxime (50 g.) was refluxed with acetic anhydride (300 c.c.) and anhydrous sodium acetate for 2 hours, but the resulting oil, worked up in the usual way, did not give a high-boiling fraction which solidified. The total distillates were therefore mixed and subjected to hydrolysis by 70% sulphuric acid. The product, after extraction with ether on cooling, was made strongly alkaline and steam-distilled. A solid which collected was found to be unchanged oxime, which is therefore not only resistant to the action of acetic anhydride, but is also soluble in the acid solution employed for hydrolysis.

When the work was repeated with longer refluxing with acetic anhydride (8 hours), a base was obtained, b. p. 230—234°/765 mm., but some piperitoneoxime still persisted unchanged and separated as a solid towards the end of the steam-distillation. The yield of oil obtained in the best experiments did not equal those experienced in the case of 4-*iso*propyl-Δ^2-*cyclo*hexen-1-one. The product gave the reactions of a primary aromatic base, and on treatment with acetyl chloride gave an acetyl derivative which crystallised from water or light petroleum in long silky needles, m. p. 111° (Found: N, 7·35. Calc. for $C_{12}H_{17}ON$: N, 7·3%). The base is therefore thymylamine (3-methyl-6-*iso*propylaniline) (compare Widman, *Ber.*, 1882, **15**, 169).

Thymylamine oxalate was precipitated on addition of a saturated aqueous solution of oxalic acid to the base and obtained in fine white needles, m. p. 169°, on recrystallisation from dilute alcohol (Found: C, 68·2; H, 8·3; N, 7·25. $2C_{10}H_{15}N,H_2C_2O_4$ requires C, 68·0; H, 8·2; N, 7·2%).

Carvacrylamine from Carvoxime.—Carvoxime was best prepared by refluxing carvone (55 g.) with hydroxylamine hydrochloride (28 g.) for 4 hours in alcoholic solution with anhydrous sodium acetate. After removal of the major part of the alcohol and steam-distillation the oxime collected as a solid, which separated in glistening plates (50 g.), m. p. 73°, on recrystallisation from dilute alcohol.

The oxime was refluxed for 8 hours with acetic anhydride (10 parts) and anhydrous sodium acetate; the oil which was precipitated when the mixture was poured into water soon solidified. Part of the solid, recrystallised from water (norit), separated in white needles, m. p. 64°, which after recrystallisation from aqueous acetone gave glistening plates, m. p. 65—66°. It was identified as carvoxime acetate (Found: C, 69·6; H, 8·2; N, 6·8. Calc.: C, 69·6; H, 8·2; N, 6·8%) (compare Rupe, *Annalen*, 1913, **395**, 137).

When the major part of the crude solid was submitted to the usual hydrolytic and steam-distillation treatment, only a small quantity of an oily base was obtained. It was identified as carvacrylamine (2-methyl-5-*iso*propylaniline) by the preparation of its benzoyl derivative, which, crystallised from dilute alcohol and then from light petroleum, separated in fine white needles, m. p. 98° (Found: C, 80·3; H, 7·6; N, 5·6. Calc. for $C_{17}H_{19}ON$: C, 80·6; H, 7·5; N, 5·5%). The *iso*propenyl group becomes saturated in this case as in several other reactions with this oxime.

The large yield of carvoxime acetate shows this oxime to be extremely resistant to the action of acetic anhydride.

A slightly improved yield of the base was obtained in a further experiment in which refluxing with the anhydride was continued for 24 hours, but even under these conditions unchanged carvoxime acetate persisted. The base was further identified by its hydrochloride, obtained in glistening plates, m. p. 210°, and by the *oxalate* (prepared as described in the preceding case), which separated in glistening plates, m. p. 150°, from dilute alcohol (Found: N, 7·25. $2C_{10}H_{15}N,H_2C_2O_4$ requires N, 7·2%).

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334. *The Colouring Matters of* Drosera Whittakeri. *Part V. The Constitution of Droserone.*

By J. W. H. Lugg, A. Killen Macbeth, and F. L. Winzor.

The structure—2 : 5(or 2 : 8)-dihydroxy-1 : 4-naphthaquinone—proposed for droserone has now been supported by the measurement of its normal reduction potential. This is in good agreement with values calculated from data previously obtained (*J.*, 1936, 1457) and shows the close relationship to hydroxyjuglone on the one hand and phthiocol on the other.

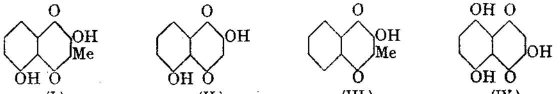
The 1 : 4-naphthaquinone structure of droserone is shown by the characteristic absorption spectrum of its acetate, and its relationship to hydroxyjuglone is further shown by the similarity of the spectra of the colouring matters and their acetates. The absorption spectra of phthiocol and naphthapurpurin and their acetates are also discussed, showing their relationship to lawsone and hydroxydroserone respectively.

The isolation of pure droserone from the natural source is described.

In previous papers (J., 1935, 325, 334) it was shown that hydroxydroserone, one of the colouring matters of *Drosera Whittakeri*, was 3 : 5 : 8-trihydroxy-2-methyl-1 : 4-naphthaquinone; a fact which was verified by synthesis (*ibid.*, p. 336). The associated dye, droserone, was considered to be the corresponding 3 : 5(or 3 : 8)-dihydroxy-compound, as it formed only a monoboroacetate and gave a pyridine salt. Droserone of sufficient purity for the examination of its reduction potential and the study of its absorption spectrum has now been prepared.

The reduction potentials of a large number of naphthaquinones were measured by Lugg, Macbeth, and Winzor (J., 1936, 1457), and from the data recorded a value of the normal reduction potential of droserone may be derived. On the assumption that the hydroxyl groups in droserone (I) occupy the same relative positions as in hydroxyjuglone (II), the value of the normal reduction potential of the former is obtained by adding the effect of the substituted 2-methyl group (— 0·0628 volt) to the observed reduction potential of the latter (0·3149 volt). This gives a calculated value of 0·2521 volt, but the method makes no allowance for any effect the substituent methyl group may exert on the tautomerism, if any, of the hydroxyjuglone system.

An alternative result may be derived by considering the effect of introducing a 5-hydroxyl group (— 0·0373 volt) into phthiocol (III) (0·2992 volt). The resultant value, 0·2619 volt, does not differentiate between the 2 : 5- and the 2 : 8-isomeride, and the actual value may also be influenced by tautomeric changes consequent on the introduction of a second hydroxyl group.



(I.) (II.) (III.) (IV.)

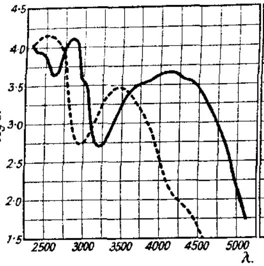
The experimental values of the normal reduction potential of droserone obtained by three different titration methods (0·2576, 0·2585, 0·2598 volt) are in good agreement with the calculated values, showing a maximum difference of some 8 millivolts only: and the proposed structure of the colouring matter thus derives considerable support.

Macbeth, Price, and Winzor (J., 1935, 325) showed that, although the introduction of hydroxyl groups in most cases modifies the typical spectrum of 1 : 4-naphthaquinone, the curves of the acetates revert to a form which closely resembles the simple 1 : 4-naphthaquinone type. The examination of the acetoxy-derivatives therefore provides a method for detecting this particular structure, and the absorption spectrum of droserone diacetate conforms to the 1 : 4-naphthaquinone type.

The close relationship between the structures of droserone and hydroxyjuglone is further

shown by the similarity in the absorption spectra of the compounds and their acetates. The colouring matters themselves show two well-marked bands and a well-defined inflexion, which are at similar locations and are of corresponding intensities. The same holds good

FIG. 1.



—— *Hydroxyjuglone*
---- *Hydroxyjuglone diacetate*

FIG. 2.

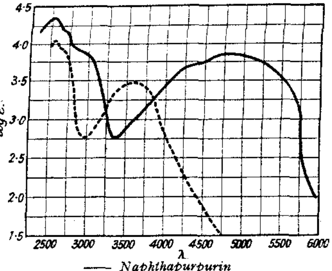
—— *Droserone*
---- *Droserone diacetate*

	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.
Droserone	4100	3·7	2880	4·1	*ca. 2500*	4·0
Hydroxyjuglone	4080	3·66	2860	4·12	*ca. 2400*	3·96
Droserone diacetate	3440	3·5	2675	3·96		
Hydroxyjuglone diacetate	3460	3·48	2500	4·06		

in the case of the acetates, which show two similarly placed maxima, one of which in the case of hydroxyjuglone diacetate, however, covers a wider region than the corresponding band of droserone diacetate (Figs. 1 and 2).

Macbeth, Price, and Winzor (*loc. cit.*) directed attention to the fact that the acetates of naphthazarin, methylnaphthazarin, and hydroxydroserone all showed a maximum at λ3520 A. of like intensities. The presence of the *peri*-hydroxyl groups in hydroxydroserone was deduced on such grounds, and further data on this point are now available in the case of naphthapurpurin (IV) and its acetate (Fig. 3). The structures of naphthapurpurin and hydroxydroserone are closely related, and this is reflected in the spectra of the compounds and their acetates (table below).

FIG. 3.



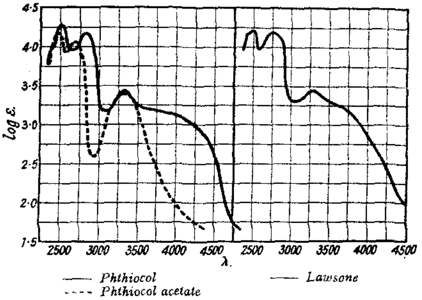
—— *Naphthapurpurin*
---- *Naphthapurpurin triacetate*

The absorption spectrum of phthiocol closely resembles that of lawsone (2-hydroxy-1 : 4-naphthaquinone), the effect of the substituent methyl group expressing itself as a slight increase in the general absorption in the regions of longer wavelength. Similar maxima are found in the case of the two acetates, an inflexion in the

	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.
Naphthapurpurin	4860	3·86	*ca. 2900*	3·9	2530	4·3
Hydroxydroserone	4880	3·83	2980	3·92	*ca. 2550*	3·95
Naphthapurpurin triacetate	3550	3·48	2540	4·06		
Hydroxydroserone triacetate	3510	3·48	2600	4·06		

absorption curve of lawsone acetate being magnified into a definite band, similarly located, in the spectrum of phthiocol acetate (Fig. 4).

FIG. 4.



	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.	$\lambda_{max.}$, A.	log ε.
Phthiocol	2500	4·28	2810	4·18	3510	3·44
Lawsone	2490	4·24	2760	4·2	3310	3·45
Phthiocol acetate	2480	4·18	2670	4·06	3330	3·4
Lawsone acetate	2480	4·26	*ca.* 2620	4·14	3330	3·41

EXPERIMENTAL.

Preparation of Pure Droserone.—The air-dried bulbs of *Drosera Whittakeri* were repeatedly extracted with boiling alcohol until the extract was practically colourless. After hot filtration fatty substance settled on cooling, and after decantation and removal of the bulk of alcohol the crude colouring matters were precipitated by pouring the residue into water. After drying, the crude dyes were sublimed, the process being repeated if necessary. On fractional crystallisation from glacial acetic acid the droserone was retained in the mother-liquors, and the crude material obtained by precipitation with water was, after drying, acetylated by short refluxing with acetic anhydride and anhydrous zinc chloride. Hydroxydroserone triacetate was recovered by fractional crystallisation of the acetates, first from glacial and then from dilute acetic acid. The crude product obtained by pouring the mother-liquors into water was hydrolysed by boiling with dilute sodium hydroxide solution, and after crystallisation from acetic acid was reacetylated as before. An equal volume of glacial acetic acid was added to the hot acetic anhydride solution; on cooling, a further yield of impure hydroxydroserone triacetate crystals separated. The mother-liquors were poured into water and the product after deacetylation by dilute alkali was obtained in light red needles, m. p. 174°, on recrystallisation from dilute alcohol. The crystals were suspended in water, and dioxan was added until at the boiling point the substance was practically all dissolved. A few drops of 5% sulphuric acid–dichromate solution were added to oxidise traces of hydroxydroserone, and boiling was continued for a few minutes. Dull yellow needles separated on cooling, and the product gave, after recrystallisation from acetic acid (norit), pale yellow needles, m. p. 181°.

Droserone diacetate was prepared by heating droserone with acetic anhydride and a little anhydrous zinc chloride. It separated in pale yellow needles, m. p. 119°, from methyl alcohol (Found: C, 62·35; H, 4·1. $C_{15}H_{12}O_6$ requires C, 62·5; H, 4·15%).

Reduction Potential of Droserone.—The solubility and the normal reduction potentials of droserone were determined at 25° by the method and in the solvent (50% aqueous alcohol containing 0·1*M*-hydrogen chloride and 0·2*M*-lithium chloride) described in the previous work (*loc. cit.*). The reduction of the droserone for electrometric titration could not be effected without the aid of the platinum–platinum oxide catalyst, and the usual quinone destruction was encountered—ranging from 13 to 22% in the various titrations. The potentials were established quickly and were well poised. The normal reduction potentials, recorded in reference to the

hydrogen electrode at 760 mm. Hg total pressure of hydrogen and solvent vapour, were 0·2576 volt (titration with benzoquinone, ΔE_1 19·7 mv.; ΔE_2 20 mv.), 0·2585 volt (titration with juglone, ΔE_1 18·4 mv.; ΔE_2 19·4 mv.), and 0·2598 volt (titration with 1 : 4-naphthaquinone, ΔE_1 18·1 mv.; ΔE_2 19·3 mv.). The solubility of droserone in the experimental solvent was 5·1 millimols. per l.

Naphthapurpurin was obtained in better yield by substituting for the 1 : 2 : 4-trihydroxybenzene used in the previous preparation (Macbeth, Price, and Winzor, *loc. cit.*) the trimethyl ether prepared by treating hydroxyquinol triacetate in methyl alcohol with sodium hydroxide and a large excess of methyl sulphate. The naphthapurpurin was crystallised from benzene.

Naphthapurpurin triacetate is difficult to obtain pure, as the reaction mixture readily becomes a tarry mass, and the acetate is extremely susceptible to slight hydrolysis with consequent deepening in colour. It was isolated on treatment of pure naphthapurpurin with acetic anhydride and a *small* fragment of anhydrous zinc chloride. It crystallised from methyl alcohol in brownish-orange needles, m. p. 164° (Found: C, 57·6; H, 3·9. $C_{16}H_{12}O_8$ requires C, 57·8; H, 3·6%).

Phthiocol was prepared from 2-methyl-1 : 4-naphthaquinone through 1 : 4-diketo-2-methyltetrahydronaphthalene-2 : 3-oxide (Madinareita, *Anal. Fis. Quim.*, 1933, **31**, 750). The oxide itself was best prepared by treating a solution of 2-methyl-1 : 4-naphthaquinone (3·4 g.) in methyl alcohol with 30% hydrogen peroxide (13 c.c.) and 2*N*-sodium hydroxide (20 c.c.). The mixture, which became warm, was kept for 15 minutes, diluted slightly with water, and neutralised with dilute sulphuric acid. The oxide separated in fine white needles, m. p. 102° after recrystallisation from ethyl alcohol.

Phthiocol acetate, obtained by acetylation of phthiocol with acetic anhydride and zinc chloride, crystallised from dilute methyl alcohol in almost white needles, m. p. 106°.

Hydroxyjuglone diacetate was obtained by refluxing for a few minutes hydroxyjuglone with acetic anhydride (4 parts) and a fragment of anhydrous zinc chloride. On cooling, the mixture was poured into water; the acetate, recrystallised from methyl alcohol, formed pale yellow needles, m. p. 137° (Found: C, 61·0; H, 3·85. $C_{14}H_{10}O_6$ requires C, 61·3; H, 3·65%).

THE JOHNSON CHEMICAL LABORATORIES,
UNIVERSITY OF ADELAIDE. [*Received, August 16th*, 1937.]

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335. 2 : 5-*Dimethyl Xylofuranose and* 2 : 3-*Dimethyl Xylose.*

By GEORGE J. ROBERTSON and DAVID GALL.

IN the course of a research (unpublished) on the conversion of xylose into an isomeric pentose by means of optical inversions within the molecule, material became available for the preparation of 2 : 5-*dimethyl xylofuranose* and 2 : 3-dimethyl xylose. The former sugar has now been prepared for the first time; the latter, which has only been obtained from a natural source by the hydrolysis of methylated xylan (Hampton, Haworth, and Hirst, J., 1929, 1739), has now been prepared by synthetic methods. Of all the mono- and di-methyl derivatives of xylose which may be expected to exist, only 4-methyl xylose and 3 : 5-dimethyl xylofuranose (known in the form of a lactone) remain to be prepared.

Convenient starting points were found in 3-*p*-toluenesulphonyl 5-benzoyl 1 : 2-monoacetone xylose and 5-benzoyl 1 : 2-monoacetone xylose, which may be obtained by the methods of Svanberg and Sjöberg (*Ber.*, 1923, **56**, 863, 1448) and Levene and Raymond (*J. Biol. Chem.*, 1933, **102**, 317).

2 : 5-*Dimethyl Xylofuranose*.—The benzoyl group was removed from 3-*p*-toluenesulphonyl 5-benzoyl 1 : 2-monoacetone xylose by treatment with sodium methoxide, and 3-p-*toluenesulphonyl* 1 : 2-*monoacetone xylose* was obtained in crystalline form, which, on methylation with the Purdie reagents, gave a theoretical yield of crystalline 3-p-*toluenesulphonyl* 1 : 2-*monoacetone* 5-*methyl xylose*. This substance, on treatment with methyl-alcoholic hydrogen chloride, yielded a mixture of 3-p-*toluenesulphonyl* 5-*methyl* γ-*methylxylosides* which was separated into crystalline 3-p-*toluenesulphonyl* 5-*methyl* β-*methylxylofuranoside* and a syrup which was essentially the corresponding α-*methylxylofuranoside*. Moreover, it was possible, by means of treatment with methyl-alcoholic hydrogen chloride, to convert the syrupy

α-form into an equilibrium mixture from which the pure β-form could be isolated and *vice versa*.

The α- and the β-form of 3-*p*-toluenesulphonyl 5-methyl methylxylofuranoside were converted successively into the corresponding 3-p-*toluenesulphonyl* 2 : 5-*dimethyl methylxylofuranosides* and 2 : 5-*dimethyl methylxylofuranosides* and finally into 2 : 5-*dimethyl xylofuranose*. The same final product was obtained in each series of experiments. The structure assigned to the resultant sugar was proved by its conversion into the *p*-bromophenylosazone of 5-methyl xylose, identical with that obtained by Levene and Raymond (*loc. cit.*, p. 331).

2 : 3-*Dimethyl Xylose*.—5-Benzoyl monoacetone xylose was converted successively into 5-benzoyl γ-methylxyloside, 5-*benzoyl* 2 : 3-*dimethyl γ-methylxyloside*, 2 : 3-*dimethyl γ-methylxyloside*, and so into 2 : 3-dimethyl xylose. The identity of the sugar was proved by its conversion into 2 : 3-dimethyl β-methylxyloside and 4-*p*-toluenesulphonyl 2 : 3-dimethyl β-methylxyloside (Robertson and Speedie, J., 1934, 829). It is noteworthy that there was no indication of acyl migration during the methylation of 5-benzoyl γ-methylxyloside.

A similar synthesis was attempted from 5-*p*-toluenesulphonyl 1 : 2-monoacetone xylose *via* 5-p-*toluenesulphonyl 3-methyl* 1 : 2-*monoacetone xylose*. This substance was treated with methyl-alcoholic hydrogen chloride to effect removal of the acetone residue and its replacement with the methylxylosidic group. Unexpectedly, the *p*-toluenesulphonyl residue was eliminated at the same time, and the resulting product was a monomethyl methylxyloside. Similar experiments with 5-*p*-toluenesulphonyl 1 : 2-monoacetone xylose confirmed the unusual behaviour of the *p*-toluenesulphonyl group in position 5.

EXPERIMENTAL.

Xylose was converted successively into diacetone xylose and 1 : 2-monoacetone xylose as described by Svanberg and Sjöberg (*loc. cit.*). The latter was converted into 3-*p*-toluenesulphonyl 5-benzoyl 1 : 2-monoacetone xylose, and 5-benzoyl 1 : 2-monoacetone xylose by the methods of Levene and Raymond (*loc. cit.*).

3-p-*Toluenesulphonyl* 1 : 2-*Monoacetone Xylose*.—3-*p*-Toluenesulphonyl 5-benzoyl 1 : 2-monoacetone xylose (10 g.) was dissolved in benzene (100 c.c.), and a solution of sodium (0·3 g.) in methyl alcohol (15 c.c.) added. The resulting homogeneous solution was kept at room temperature for 1 hour, then poured into water (100 c.c.). The benzene layer was separated, washed with dilute acid and water, dried, and evaporated to dryness. The product (6 g.) crystallised on cooling. On recrystallisation from ethyl alcohol–light petroleum, 3-p-*toluenesulphonyl* 1 : 2-*monoacetone xylose* was obtained as fine needles, m. p. 89—90°; $[\alpha]_D^{17°}$ − 28·6° in chloroform (*c* = 2) (Found : S, 9·28. $C_{15}H_{20}O_7S$ requires S, 9·3%).

3-p-*Toluenesulphonyl* 1 : 2-*Monoacetone* 5-*Methyl Xylose*.—This substance was prepared in theoretical yield by methylating the above compound with methyl iodide and silver oxide. It crystallised from light petroleum (b. p. 80—100°) in needles, m. p. 81—82°, $[\alpha]_D^{18°}$ − 31·8° in chloroform (*c* = 2·412) (Found : MeO, 8·6. $C_{16}H_{22}O_7S$ requires MeO, 8·66%).

3-p-*Toluenesulphonyl* 5-*Methyl γ-Methylxylosides*.—The foregoing compound (2·5 g.), dissolved in methyl alcohol (150 c.c.) containing dry hydrogen chloride (4·5 g.), was kept at room temperature till no further change in rotation was observed. The initial value, $[\alpha]_D$ − 18·9°, changed to a constant value of + 11·3° (corrected for change in concentration) in 24 hours. The solution was neutralised with lead carbonate, filtered, and evaporated to dryness. The residue was extracted with ether, and the ethereal extract, after being decolorised with charcoal, was evaporated to give a clear syrup (2·0 g.) which partly crystallised on standing. On crystallising this material from ether–light petroleum (b. p. 40—60°), and then from carbon tetrachloride, 3-p-*toluenesulphonyl* 5-*methyl β-methylxylofuranoside* was obtained as colourless plates (0·8 g.), m. p. 89°, $[\alpha]_D^{18°}$ − 51·7° in chloroform (*c* = 1·798) (Found : MeO, 18·9. $C_{14}H_{20}O_7S$ requires MeO, 18·97%).

The mother-liquors from the above crystallisations yielded a syrup (1·1 g.), which had the same empirical composition as the crystals described above, but differed markedly in showing $[\alpha]_D^{17°}$ + 44·5° in chloroform (*c* = 2·207). This material is probably contaminated with traces of the β-form but is essentially 3-p-*toluenesulphonyl* 5-*methyl α-methylxylofuranoside* (Found : MeO, 18·78%).

A larger-scale experiment, in which 12 g. of starting material were used, gave the same end

point, $[\alpha]_D$ − 19·2° ⟶ + 11° (corrected), and yielded 4·2 g. of crystalline β-form along with 6·5 g. of the syrupy α-form.

Interconversion of the α- and the β-Form of 3-p-Toluenesulphonyl 5-Methyl Methylxylofuranoside. —The α-form (0·52 g.), purified as far as possible from the crystalline isomer and showing $[\alpha]_D^{17°}$ + 44·5° in chloroform, was dissolved in methyl alcohol (20 c.c.). The rotation of the solution was $[\alpha]_D^{17°}$ + 26·3°. After addition of a 10% solution of hydrogen chloride in methyl alcohol (1 c.c.), the solution was maintained at room temperature, and the course of the reaction observed polarimetrically. The rotation gradually fell, and after 48 hours was constant at + 11·7°. When the product was isolated as described above, 0·2 g. of the crystalline β-form was obtained on crystallisation.

In the same way the pure β-form was converted into an equilibrium mixture, $[\alpha]_D$ + 11·7°, from which a specimen of the α-form could be isolated. Unsuccessful attempts were made to change the equilibrium point by changing the conditions of reaction. The configuration of the methylxylosidic group in the two forms was determined by studying the hydrolysis of the 2 : 5-dimethyl methylxylofuranosides derived from them (see below).

3-p-*Toluenesulphonyl* 2 : 5-*Dimethyl Methylxylofuranosides*.—3-*p*-Toluenesulphonyl 5-methyl β-methylxylofuranoside was methylated by means of the Purdie reagents. After 12 such treatments, the 2 : 5-*dimethyl* compound was obtained in 70% yield as a colourless viscous syrup, $[\alpha]_D^{18°}$ − 49·9° in chloroform (c = 1·794), $n_D^{18°}$ 1·5037 (Found : MeO, 26·8. $C_{15}H_{22}O_7S$ requires MeO, 26·8%).

In similar fashion methylation of the syrupy α-isomer (20 treatments) yielded 3-p-*toluenesulphonyl* 2 : 5-*dimethyl α-methylxylofuranoside* as a viscous syrup which showed $[\alpha]_D^{17°}$ + 34·7° in chloroform (c = 1·976), $n_D^{18°}$ 1·5050 (Found : MeO, 26·1%).

2 : 5-*Dimethyl Methylxylofuranosides*.—3-*p*-Toluenesulphonyl 2 : 5-dimethyl β-methylxylofuranoside (7 g.) was dissolved in ethyl alcohol (50 c.c.), and a solution of potassium hydroxide (7·5 g.) in water (100 c.c.) added. The mixture was boiled for 10 hours. Polarimetric control was impossible owing to the rapid darkening of the solution. The alkali was neutralised with carbon dioxide, and the solvent removed under diminished pressure. The dry residue was extracted with ether, and the ethereal extract, on evaporation, yielded a dark syrup (3·1 g.), which on distillation gave 2 : 5-*dimethyl β-methylxylofuranoside* as a mobile colourless syrup (2·5 g.), b. p. 85° (bath temp.)/0·02 mm., $n_D^{17°}$ 1·4501, $[\alpha]_D^{17°}$ − 56° in chloroform (c = 2·26) (Found : MeO, 47·8. $C_8H_{16}O_5$ requires MeO, 48·4%).

In similar fashion, the α-methylxylofuranoside (5·3 g.) was converted into 2 : 5-*dimethyl α-methylxylofuranoside*, which was obtained as a colourless syrup (1·7 g.), b. p. 110° (bath temp.)/ 0·03 mm., $n_D^{18°}$ 1·4507, $[\alpha]_D^{17°}$ + 54·3° in chloroform (c = 2·696) (Found : MeO, 47·5%).

2 : 5-*Dimethyl Xylofuranose*.—2 : 5-Dimethyl β-methylxylofuranoside (2 g.) was dissolved in a mixture of water (75 c.c.), acetone (75 c.c.), and hydrogen chloride (4·5 g.). The hydrolysis was observed polarimetrically and was carried out at room temperature. The initial rotation $[\alpha]_D$ − 49·1° changed in 10 hours to a constant value of + 32·4° (corrected for change in concentration). The solution was neutralised with lead carbonate, filtered, and evaporated to dryness. Extraction of the dry residue with acetone, followed by evaporation to dryness, yielded 2 : 5-*dimethyl xylofuranose* as a viscous syrup, which reduced Fehling's solution on warming and showed $n_D^{14°}$ 1·4706, $[\alpha]_D^{17°}$ + 46° in water (c = 1·21) and + 16·4° in ethyl alcohol (c = 1·85) (Found : MeO, 34·0. $C_7H_{14}O_5$ requires MeO, 34·8%).

When 2 : 5-dimethyl α-methylxylofuranoside (1·3 g.) was submitted to similar treatment, the initial rotation $[\alpha]_D$ + 32·3° changed to a constant value of + 27° (corrected for change in concentration) in 5 hours. In this experiment, however, a different proportion of acetone and water was used, and this accounts for the discrepancy in the value of the end point. The product was isolated as above, and the 2 : 5-dimethyl xylofuranose so obtained showed $n_D^{17°}$ 1·4699, $[\alpha]_D^{16°}$ + 16·6° in ethyl alcohol (c = 1·327) (Found : MeO, 33·8%).

The results of the above hydrolyses corroborate the configurations assigned to the two series of xylofuranosides which have been described.

Conversion of 2 : 5-Dimethyl Xylofuranose into the p-*Bromophenylosazone of 5-Methyl Xylose*.— 2 : 5-Dimethyl xylofuranose (0·3 g.) was dissolved in water (20 c.c.), and *p*-bromophenylhydrazine (0·8 g.) in 10% acetic acid (8 c.c.) added. The mixture was heated at 60° for an hour, after which the temperature was gradually raised to 90° and maintained at that point for 1½ hours. The osazone, together with a large amount of tarry material, separated, and after cooling, the aqueous liquor was decanted. Several crystallisations from ethyl alcohol and finally from ether were necessary to free the osazone from tarry material. The *p*-bromophenylosazone was finally obtained as flat, blunt, yellow-brown needles (0·04 g.), m. p. 167—169° (decomp.). Levene

and Raymond quote m. p. 170—171° (Found: MeO, 6·2. Calc. for $C_{18}H_{20}O_3N_4Br_2$: MeO, 6·2%).

5-*Benzoyl γ-Methylxyloside.*—5-Benzoyl 1 : 2-monoacetone xylose (5 g.) was dissolved in methyl alcohol (60 c.c.) containing hydrogen chloride (0·6 g.), and the solution was boiled until the rotation became constant. The hot solution was neutralised with lead carbonate, cooled, filtered, and evaporated to dryness. The residue was extracted with boiling chloroform, and after filtration and evaporation, a mixture of the α- and the β-form of 5-benzoyl γ-methylxyloside was obtained as a yellow syrup (4·2 g.). The product was contaminated with methyl benzoate, but it was decided to remove this impurity at a later stage.

5-*Benzoyl* 2 : 3-*Dimethyl γ-Methylxyloside.*—The mixture of 5-benzoyl γ-methylxylosides (17·5 g.) was methylated three times with methyl iodide and silver oxide. The resulting syrup, $n_D^{15°}$ 1·4920, was dissolved in benzene, and the solution repeatedly extracted with water to remove trimethyl γ-methylxyloside which might have resulted through the loss of benzoyl content and consequent exposure of the hydroxyl group to methylation. The benzene solution, after drying over anhydrous sodium sulphate and evaporation, yielded a mixture of the α- and the β-form of 5-*benzoyl* 2 : 3-*dimethyl γ-methylxyloside* as a mobile syrup (16·3 g.), $n_D^{15°}$ 1·4918 (Found: MeO, 32·3. $C_{15}H_{20}O_6$ requires MeO, 31·4%). The high methoxyl value is undoubtedly due to the persistence of traces of methyl benzoate in the product.

2 : 3-*Dimethyl γ-Methylxyloside.*—The benzoyl group was removed from 5-benzoyl 2 : 3-dimethyl γ-methylxyloside (18 g.) by boiling it for 1 hour with *N*/5-aqueous-alcoholic sodium hydroxide solution. The reaction mixture was diluted with water, and the alcohol evaporated; the aqueous residue was almost saturated with potassium carbonate and extracted repeatedly with chloroform; the combined extracts were dried and evaporated to dryness. As the resulting syrup might contain unchanged material in addition to the desired product, it was dissolved in benzene, and the solution extracted repeatedly with water until an aqueous extract showed no optical activity. The combined aqueous extracts were almost saturated with potassium carbonate and exhaustively extracted with chloroform. The combined chloroform extracts, on drying and evaporation, yielded a syrup (7·7 g.), which was distilled to give 2 : 3-*dimethyl γ-methylxyloside* (6·5 g.) as a colourless mobile syrup, b. p. 95° (bath temp.)/0·15 mm., $n_D^{16°}$ 1·4518, and $[\alpha]_D^{16°}$ + 12·5° in chloroform (*c* = 2·104) (Found: MeO, 48·9. $C_8H_{16}O_5$ requires MeO, 48·4%).

2 : 3-*Dimethyl Xylose.*—2 : 3-Dimethyl γ-methylxyloside (5·8 g.) was hydrolysed by boiling with *N*/10-hydrochloric acid (200 c.c.). The initial rotation, $[\alpha]_D$ + 16·7°, changed to a constant value of + 22·3° (corrected for change in concentration) in 90 mins. The hot solution was neutralised with lead carbonate, filtered, and evaporated, and the residue was extracted with hot acetone. On evaporation of the acetone, 2 : 3-dimethyl xylose (4·8 g.) was obtained as a pale yellow syrup, which showed $n_D^{16°}$ 1·4727, and $[\alpha]_D$ + 18·9° changing to + 19·6° in chloroform (*c* = 1·7) (Found: MeO, 34·6. Calc. for $C_7H_{14}O_5$: MeO, 34·8%). The above constants are almost identical with those quoted by Robertson and Speedie (*loc. cit.*) for 2 : 3-dimethyl xylose obtained from xylan by the method of Hampton, Haworth, and Hirst (*loc. cit.*).

2 : 3-Dimethyl xylose was characterised by conversion into 2 : 3-dimethyl β-methylxyloside and 4-*p*-toluenesulphonyl 2 : 3-dimethyl β-methylxyloside by the methods described by Robertson and Speedie (*loc. cit.*).

2 : 3-Dimethyl β-methylxyloside was a clear syrup, b. p. 95° (bath temp.)/0·03 mm., $n_D^{17°}$ 1·4538, $[\alpha]_D^{18°}$ − 5·7° in chloroform (*c* = 1·8) (Found: MeO, 48·1. Calc. for $C_8H_{16}O_5$: MeO, 48·4%). The material prepared from xylan showed b. p. 90—95° (bath temp.)/0·03 mm., n_D^{15} 1·4540, $[\alpha]_D$ − 5·8° in chloroform (*c* = 2·20).

4-*p*-Toluenesulphonyl 2 : 3-dimethyl β-methylxyloside was a crystalline solid, m. p. 59—60°, $[\alpha]_D^{17°}$ −8·5° in chloroform (*c* = 1·2). Robertson and Speedie quote m. p. 56—59°, $[\alpha]_D$ − 8·8° in chloroform (*c* = 2·50) for the same substance derived from xylan.

5-p-*Toluenesulphonyl Monoacetone* 3-*Methyl Xylose.*—5-*p*-Toluenesulphonyl 1 : 2-monoacetone xylose, prepared by the method of Levene and Raymond (*loc. cit.*), was converted into 5-p-*toluenesulphonyl monoacetone* 3-*methyl xylose* by methylation with the Purdie reagents. It crystallised from methyl alcohol in needles, m. p. 114°, $[\alpha]_D$ − 27·2° in chloroform (*c* = 2·173) (Found: MeO, 8·6. $C_{16}H_{22}O_7S$ requires MeO, 8·66%).

Treatment of 5-p-*Toluenesulphonyl Monoacetone* 3-*Methyl Xylose with Methyl Alcohol containing Hydrogen Chloride.*—The material (4·0 g.), dissolved in methyl alcohol (100 c.c.) containing dry hydrogen chloride (1 g.), was kept at room temperature for 10 hours. No polarimetric observation was possible owing to the rapid development of colour. The solution was neutralised with lead carbonate, filtered, and evaporated to dryness. The resultant syrup

(1·2 g.) was taken up in ether, boiled with norit, filtered, and the solution evaporated. The purified product contained no sulphur and corresponded with a monomethyl methylxyloside (Found: MeO, 34·9. Calc. for $C_7H_{14}O_5$: MeO, 34·8%). The *p*-toluenesulphonyl group had been eliminated. Similar results were obtained when 5-*p*-toluenesulphonyl monoacetone xylose was submitted to the above treatment.

We are indebted to Messrs. Tullis Russell and Co., Markinch, for a generous supply of esparto cellulose. One of us (D. G.) is indebted to The Carnegie Trust for the grant of a Scholarship, which has enabled him to take part in the work.

THE UNIVERSITY, ST. ANDREWS. [*Received, May 28th*, 1937.]

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336. *The Dissociation Constants of Organic Acids. Part XIX. Some Unsaturated Acids.*

By WILLIAM L. GERMAN, GEORGE H. JEFFERY, and ARTHUR I. VOGEL.

Conductivity measurements in silica or Pyrex cells at 25° over the concentration range 0·0001—0·01*N* of the following acids and their sodium salts have been made: acrylic, *trans*-crotonic, ββ-dimethylacrylic, tetrolic, furoic, and glutaconic acids. The results for the sodium salts have been corrected for hydrolysis and the carbonic acid in the water used.

The thermodynamic dissociation constants of the monobasic acids and the primary dissociation constant of glutaconic acid have been calculated by a modification of MacInnes's method.

The true dissociation constants of the acids have also been determined by potentiometric titration with the quinhydrone electrode.

It is shown that the ratio K_1/K_2 and also the titration curve for glutaconic acid, m. p. 138°, are similar to those for fumaric acid; independent evidence for the *trans*-configuration is thus obtained.

THE present communication provides accurate conductivity data over the range 0·0001—0·01*N* for a number of unsaturated acids (and their sodium salts) of theoretical interest. These have been employed for the evaluation of the thermodynamic dissociation constants. Acrylic acid, *trans*-crotonic acid and ββ-dimethylacrylic acid give values for $K_{\text{therm.}}$ in agreement with those expected from the modern electronic theory and are in accord with the work of Ives, Linstead, and Riley (J., 1933, 561).

CH_2:CH·CO_2H	CHMe:CH·CO_2H	CMe_2:CH·CO_2H	CMe:C·CO_2H
$5·501 \times 10^{-5}$	$2·030 \times 10^{-5}$	$7·569 \times 10^{-6}$	$2·228 \times 10^{-3}$

The larger value for tetrolic acid as compared with *trans*-crotonic acid is noteworthy. Determination of the true dissociation constants have also been made by potentiometric titration with the quinhydrone electrode. The results agree with the conductivity values within 2—4%, showing that the quinhydrone electrode is trustworthy with these unsaturated acids.

Since the work was completed, independent determinations of $K_{\text{therm.}}$ for *trans*-crotonic acid (Saxton and Waters, *J. Amer. Chem. Soc.*, 1937, **59**, 1048) and acrylic acid (Dippy and Lewis, this vol., p. 1010) have been described. Saxton and Waters find $K_{\text{therm.}} = 1·97_5 \times 10^{-5}$, which is about 3% lower than our figure. Their values of Λ for the acid agree well with our own, as do also the measurements of Ives, Linstead, and Riley (*loc. cit.*), but serious divergences (*ca.* 2 units) are apparent in the conductivity figures for the sodium salt. Saxton and Waters prepared their solutions of sodium crotonate from the acid and sodium carbonate—a not altogether satisfactory procedure—and corrected the conductivities for the effect of the excess of acid. Our measurements were made with solutions prepared from pure *solid* sodium crotonate, and corrections for hydrolysis and for the carbonic acid in the equilibrium water used were applied as described in Part XI (J., 1935, 24). The

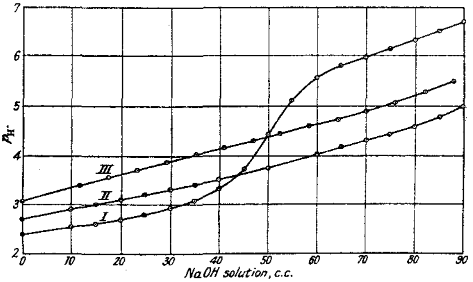
American authors give Λ_0 = **83·30** (sodium salt) and Λ_0 = **383·11** (acid; deduced from their own measurements upon hydrochloric acid and sodium chloride): our values are **84·35** and **381·84** respectively. The latter are in satisfactory agreement with the results of Ives, Linstead, and Riley (*loc. cit.*) (84·4 and 381·8 respectively).

Dippy and Lewis's conductivity figures for acrylic acid are in good agreement with our own, but they give Λ_0 = 87·5 for sodium acrylate (prepared in solution from the acid and sodium hydroxide solution), whereas we find Λ_0 = 90·62. No conductivity figures for the sodium salt are given by Dippy and Lewis, who employed a semi-empirical procedure for the determination of Λ_0 (J., 1934, 162, 1889). The difference between their value of $K_{\text{therm.}}$, 5·56 × 10^{-5} [Λ_0 = 387·1, based on their own value for Λ_0 of the sodium salt and upon MacInnes, Shedlovsky, and Longsworth's figures (*J. Amer. Chem. Soc.*, 1932, **54**, 2758) for the limiting mobilities of the sodium (50·10) and hydrogen (349·72) ions], and that of the present authors, 5·501 × 10^{-5} (Λ_0 = 388·8), is due largely to the different values of the mobilities employed in the calculations.

We find $K_{1\text{therm.}}$ for glutaconic acid by conductivity = **1·711** × 10^{-4}. The values for $K_{1\text{therm.}}$ and $K_{2\text{therm.}}$, determined by potentiometric titration with the quinhydrone electrode, together with those for maleic and fumaric acids (*Phil. Mag.*, 1936, **22**, 790), are in the following table.

Acid.	$K_{1\text{therm.}}$	$K_{2\text{therm.}}$	K_1/K_2.
Maleic	1·20 × 10^{-2}	5·95 × 10^{-7}	2·02 × 10^{-4}
Fumaric	9·57 × 10^{-4}	4·13 × 10^{-5}	23·2
Glutaconic	1·70 × 10^{-4}	8·38 × 10^{-6}	20·3

The similarity between glutaconic and fumaric acids, indicated by the ratios K_1/K_2, is clearly shown by the titration curves (figure); the abscissæ have been displaced for the



I, *Maleic acid.* II, *Fumaric acid.* III, *Glutaconic acid.*

different acids to avoid overlapping. Very strong physical evidence is thus provided for the *trans*-structure of glutaconic acid, m. p. 138°. This view is rendered highly probable by the isolation of the unstable *cis*-glutaconic acid, m. p. 136·0—136·5°, by Malachowski (*Ber.*, 1929, **62**, 1323). This author found for the classical primary dissociation constants of *cis*- and *trans*-glutaconic acid at 0° the values 1·43 × 10^{-4} and 1·74 × 10^{-4} respectively. These approximate figures alone are insufficient to establish the *cis*- and *trans*-structures of these dibasic acids (compare maleic and fumaric acids); the small difference between them would appear to indicate that the unstable acid has been largely converted into the *trans*-form during the measurements. The original view of Feist as to the isomerism of the glutaconic acids and their derivatives, now accepted, but in slightly modified form, by Thorpe (J., 1931, 547, 1015) and supported by the recent work of Kon and his collaborators (J., 1931 *et seq.*)—ordinary *cis-trans* isomerism coupled with three-carbon tautomerism—is thus confirmed by an independent method.

The dissociation constant of furoic acid found by conductivity is $6{\cdot}776 \times 10^{-4}$ and by potentiometric titration $6{\cdot}99 \times 10^{-4}$. This constant was required in connexion with the new buffer mixtures incorporating furoic acid (*Analyst*, 1937, **62**, 271); the value calculated from the buffer mixtures was $6{\cdot}70 \times 10^{-4}$.

EXPERIMENTAL.

Preparation of Materials.—All the acids (with the exception of acrylic acid) were kept over calcium chloride in vacuum desiccators for several days before use. All solvents were of analytical reagent purity and sodium-dried.

Acrylic acid. 50 G. of Schuchardt's " Acid acrylic crystallis " were distilled from a fractionating Claisen flask in an all Pyrex glass apparatus; the fraction, b. p. 140°/753 mm., m. p. 13°, was used in the determinations (Billmann, *J. pr. Chem.*, 1900, **61**, 494, gives b. p. 140·8—141°).

trans-*Crotonic acid.* A commercial sample, m. p. 72—73°, was recrystallised from light petroleum (b. p. 40—60°) and then twice from toluene. The feathery flat prisms, which tended to occlude some of the latter solvent, were powdered and left over calcium chloride in a vacuum desiccator for several days. One further recrystallisation from light petroleum (b. p. 60—80°) gave pure crotonic acid, m. p. 72·5°.

ββ-*Dimethylacrylic acid.* This was prepared by a modification of Kohn's method (*Monatsh.*, 1903, **24**, 771)—oxidation of mesityl oxide, b. p. 126—130°, with sodium hypobromite solution at 0°. The acid was recrystallised twice from hot water; m. p. 70°.

Tetrolic aicd. An adaptation of Feist's method (*Annalen*, 1906, **345**, 104) was employed. In the final purification the oily acid was extracted with 15% potassium hydroxide solution, the aqueous extract cautiously acidified with hydrochloric acid, and the separated oil extracted three times with ether after saturation with ammonium sulphate. The oil left after removal of the ether crystallised partly on keeping; it was distilled under diminished pressure. The fraction, b. p. 90—95°/5 mm., solidified completely on cooling. The solid crystallised from carbon tetrachloride in thin prisms, m. p. 78°.

Glutaconic acid. The method of Conrad and Gutzeit (*Ber.*, 1882, **15**, 284; *Annalen*, 1883, **222**, 249: compare Gutzeit and Bolam, *J. pr. Chem.*, 1896, **54**, 359; Heinrich, *Monatsh.*, 1899, **20**, 551; Ingold and Perren, J., 1921, **119**, 1591), modified in certain details, was employed. The hydrolysis of the ethyl dicarbethoxyglutaconate was conducted as follows. 66 G. of the oil were treated with 70 c.c. of concentrated hydrochloric acid and 140 c.c. of water. The mixture was refluxed for 7 hours, evaporated to a small bulk on the water-bath, and extracted six times with ether. The dried extract (anhydrous sodium sulphate) was evaporated, and the residue spread on a porous tile. The sticky residue was triturated on the tile with light petroleum (b. p. 40—60°); this treatment removed oily matter and various impurities and led to a clean product. The residue (6·5 g.), m. p. 134—136°, was recrystallised twice from ether–light petroleum (b. p. 40—60°) and melted sharply at 138° (compare Conrad and Gutzeit, *loc. cit.*, m. p. 133°; Gutzeit and Bolam, *loc. cit.*, m. p. 137—138°; Birch, J., 1930, 310, m. p. 132°; Malachowski, *loc. cit.*, m. p. 138·0—138·5°).

Furoic acid. The commercial product, m. p. 131—133°, was crystallised from boiling water (charcoal) and then had m. p. 132—133°. 100 G. of this acid, 200 g. of absolute alcohol, 200 g. of sodium-dried AnalaR benzene, and 20 g. of concentrated sulphuric acid were refluxed for 20 hours. After the usual working-up, including washing with sodium hydroxide solution to remove unchanged acid, 75 g. of pure ethyl furoate, b. p. 192°/746 mm., m. p. 38°, were obtained. A mixture of 60 g. of this ester in 120 g. of rectified spirit and 52 g. (2 mols.) of potassium hydroxide in 104 g. of water was refluxed for 16 hours, and then evaporated to dryness on the water-bath. The residue was triturated with ether, acidified with a large excess of dilute sulphuric acid at 0°, and extracted four times with ether. 49 G. of acid obtained on evaporation of the dried (anhydrous sodium sulphate) ethereal solution were recrystallised from chloroform and dried in a vacuum over calcium chloride; the product melted sharply at 132°.

Sodium salts. These were prepared by the sodium ethoxide method as employed for sodium malonamate (Part IX, J., 1934, 1102). Sodium ββ-dimethylacrylate did not separate from the absolute alcoholic solution and was precipitated by the addition of pure ether; it was purified by dissolution in absolute alcohol and precipitation with ether (Found: Na, 18·8. Calc., 18·9%). The other salts were purified by solution in a small volume of water and precipitation with absolute methyl or ethyl alcohol: sodium crotonate (ethyl alcohol) (Found: Na, 21·3. Calc., 21·3%); sodium tetrolate (ethyl alcohol) (Found: Na, 28·7. Calc., 28·8%); sodium acrylate

(methyl alcohol) (Found : Na, 24·4. Calc., 24·5%); sodium glutaconate (methyl alcohol) (Found : Na, 26·3. Calc., 26·4%); sodium furoate (ethyl alcohol) (Found : Na, 17·2. Calc., 17·2%).

General Technique and Apparatus.—This has already been described in the earlier papers of the series; the symbols have the same significance. All measurements were carried out at 25° ± 0·01°.

Conductivity Measurements.—The same Pyrex and silica glass cells as used in previous work were employed and the constants were found to be unchanged. No solvent correction was applied to the acids. For the sodium salts of the monobasic acids, a normal solvent correction was first applied (*i.e.*, the specific conductivity of the water used was subtracted from the observed conductivity), from which a preliminary value of Λ_0 and thence of $l_{0_{X'}}$ and of $K_{class.}$ was obtained. These figures were employed in the computation of the combined solvent and hydrolysis correction (J., 1933, 1642; 1934, 167; *Phil. Mag.*, 1934, 18, 904). These preliminary figures are collected below.

Acid.		$l_{0_{X'}}$.	$K_{class.}$.
Acrylic	$\Lambda_0^n = \Lambda_c + 224{\cdot}2C^{0{\cdot}580} = 88{\cdot}4$	38·6	$5{\cdot}8 \times 10^{-5}$
Crotonic	$\Lambda_0^n = \Lambda_c + 310{\cdot}4C^{0{\cdot}896} = 83{\cdot}9$	34·1	$2{\cdot}1 \times 10^{-5}$
ββ-Dimethylacrylic	$\Lambda_0^n = \Lambda_c + 357{\cdot}7C^{0{\cdot}894} = 80{\cdot}4$	30·6	$7{\cdot}9 \times 10^{-6}$
Tetrolic	$\Lambda_0^n = \Lambda_c + 397{\cdot}9C^{0{\cdot}900} = 88{\cdot}5$	38·7	$2{\cdot}5 \times 10^{-3}$
Furoic	$\Lambda_0^n = \Lambda_c + 239{\cdot}3C^{0{\cdot}771} = 84{\cdot}1$	34·3	$7{\cdot}3 \times 10^{-4}$

The method described in Part XI (J., 1935, 24) was employed for sodium glutaconate. The preliminary values, a "normal" solvent correction being used, were : $\mu_0 = \mu_c + 501C^{0{\cdot}552} = 207{\cdot}3$, whence $l_{0_{X''}} = 53{\cdot}6$ and $l_{0_{HX'}} = 28{\cdot}4$; K_2 (approx.), from the potentiometric titration curve, was taken as 1×10^{-5}. For the sodium hydrogen salt data required in the evaluation of $K_{1\text{therm.}}$, $\Lambda_0 = 80{\cdot}0$ and "x" = 78·04.

The results for the sodium salts are as follows :

Sodium acrylate (M = 94·02).

$\Lambda_0^n = \Lambda_c + 197{\cdot}6C^{0{\cdot}497}$. $\Lambda_0^n = 90{\cdot}62$. $l_{X'} = 40{\cdot}8$.

$C \times 10^4$.	$\Lambda_{obs.}$.	[H˙] × 10⁷.	$\Lambda_{corr.}$.	Λ_0^n.	$C \times 10^4$.	$\Lambda_{obs.}$.	[H˙] × 10⁷.	$\Lambda_{corr.}$.	Λ_0^n.
	Run 1.	Cell *V*.	κ = 0·789.			Run 2.	Cell *S*.	κ = 0·791.	
1·559	86·93	10·01	89·40	—	5·214	85·09	7·80	86·01	—
10·04	83·62	5·18	84·37	90·77	12·69	82·85	3·52	83·35	90·51
15·88	82·16	1·97	82·52	90·56	20·09	81·18	1·23	81·49	90·54
26·85	80·17	0·83	80·46	90·96	35·71	79·14	0·59	79·36	90·39
45·26	78·25	0·46	78·42	(91·42)	52·20	77·71	0·43	77·78	(91·48)
69·61	77·30	0·38	77·46	—	69·35	76·69	0·36	76·74	—
81·89	76·11	0·28	76·17	—	92·75	75·74	0·23	75·74	—
107·5	75·20	0·17	75·20	—					

Sodium crotonate (M = 108·04).

$\Lambda_0^n = \Lambda_c + 225{\cdot}2C^{0{\cdot}812}$. $\Lambda_0^n = 84{\cdot}35$. $l_{0_{X'}} = 34{\cdot}6$.

	Run 1.	Cell *V*.	κ = 0·819.			Run 2.	Cell *S*.	κ = 0·821.	
1·365	82·67	6·11	85·38	—	9·221	82·82	2·57	83·51	82·46
6·003	82·68	3·19	83·81	84·36	18·44	82·69	1·51	82·95	84·30
12·33	82·78	2·21	83·46	84·44	33·01	81·96	0·83	82·15	84·33
23·01	82·46	1·27	82·67	82·49	47·82	81·32	0·48	81·42	84·34
39·11	81·68	0·66	81·82	84·31	57·25	80·88	0·42	80·97	84·37
48·85	81·25	0·46	81·34	84·34	73·33	80·24	0·37	80·33	84·50
64·30	80·55	0·40	80·60	84·34	97·24	79·33	0·27	79·40	84·63
84·94	79·80	0·31	79·88	84·58					

Sodium ββ-dimethylacrylate (M = 122·05).

$\Lambda_0^n = \Lambda_c + 43{\cdot}83C^{0{\cdot}346}$. $\Lambda_0^n = 84{\cdot}44$. $l_{0_{X'}} = 34{\cdot}6$.

	Run 1.	Cell *V*.	κ = 0·850.			Run 2.	Cell *S*.	κ = 0·821.	
1·708	78·50	3·35	81·92	—	9·221	82·82	2·57	83·51	82·46
7·423	79·87	1·09	80·65	84·27	18·44	82·69	1·51	82·95	84·30
11·89	79·58	0·73	80·17	84·43	33·01	81·96	0·83	82·15	84·33
21·48	78·96	0·43	79·19	84·52	47·82	81·32	0·48	81·42	84·34
39·07	77·94	0·24	78·08	84·51	57·25	80·88	0·42	80·97	84·37
52·47	77·23	0·18	77·31	84·44	73·33	80·24	0·37	80·33	84·50
74·62	76·40	0·13	76·46	(84·81)	97·24	79·33	0·27	79·40	84·63
98·09	75·65	0·10	75·69	(84·94)					

Sodium tetrolate (M = 106·02).

$\Lambda_0^n = \Lambda_c + 254{\cdot}4C^{0{\cdot}801}$. Λ_0^n = 88·96. $l_{0X'}$ = 39·2.

$C \times 10^4$.	$\Lambda_{obs.}$.	$[H^{\cdot}] \times 10^7$.	$\Lambda_{corr.}$.	Λ_0^n.	$C \times 10^4$.	$\Lambda_{obs.}$.	$[H^{\cdot}] \times 10^7$.	$\Lambda_{corr.}$.	Λ_0^n.
	Run 1.	Cell *V*.	κ = 0·795.			Run 2.	Cell *S*.	κ = 0·791.	
1·310	88·45	19·66	88·62	—	4·251	88·17	18·71	88·40	—
6·429	87·98	17·79	88·17	88·88	9·492	87·78	17·23	87·96	88·92
10·65	87·73	16·59	87·85	88·91	16·46	87·32	15·52	87·41	88·91
20·99	87·01	14·36	87·09	88·91	26·41	86·66	13·68	86·88	88·87
37·75	86·01	12·02	86·07	89·01	42·70	85·71	11·55	85·76	89·05
46·84	85·55	11·12	85·59	89·05	57·31	84·94	10·44	84·96	89·04
68·17	84·52	9·55	84·54	(89·23)	78·44	84·16	9·01	84·17	—
87·06	83·82	8·41	83·83	(89·96)	99·72	83·59	7·59	83·59	—

Sodium furoate (M = 134·02).

$\Lambda_0^n = \Lambda_c + 119{\cdot}7C^{0{\cdot}707}$. Λ_0^n = 84·80. $l_{0X'}$ = 35·0.

	Run 1.	Cell *V*.	κ = 0·760.			Run 2.	Cell *S*.	κ = 0·765.	
1·336	83·84	17·6	84·29	—	3·331	83·63	16·2	83·96	—
6·110	83·39	13·3	83·74	84·80	8·712	83·06	11·3	83·33	84·70
11·65	82·52	9·81	82·85	84·53	18·51	82·17	8·42	82·39	84·71
25·48	81·65	8·11	81·80	84·72	33·44	81·19	7·21	81·33	84·87
41·02	80·82	6·72	80·94	85·04	47·68	80·48	6·19	80·60	(85·15)
53·75	80·35	5·60	80·45	(85·44)	61·89	79·93	5·31	80·02	—
69·31	79·74	4·91	79·80	(85·74)	77·12	79·48	4·62	79·56	—
92·24	79·15	3·98	79·20	—	87·72	79·19	4·02	79·24	—

Sodium glutaconate (M = 174·03).

$\mu_0^n = \mu_c + 406{\cdot}8C^{0{\cdot}470}$. μ_0^n = 213·58. $l_{0X'}$ = 57·0. $l_{0HX'}$ = 30·2.

	Run 1.	Cell *V*.	κ = 0·638.			Run 2.	Cell *S*.	κ = 0·662.	
0·881	202·62	4·91	209·46	—	5·182	200·52	1·32	202·75	213·35
2·557	202·08	2·49	205·13	—	12·46	195·21	0·74	196·53	213·80
8·854	197·09	0·97	198·65	213·55	22·39	187·97	0·41	190·68	213·58
16·07	193·03	0·57	193·43	213·23	31·33	186·58	0·28	187·01	213·60
24·93	188·95	0·36	189·33	213·63	43·76	183·22	0·22	183·40	213·72
37·21	185·27	0·24	185·49	213·79	57·36	180·81	0·19	181·02	(216·92)
49·15	182·14	0·21	182·34	(215·74)	79·98	178·84	0·14	178·91	—
65·48	179·91	0·17	180·08	(214·38)	98·64	177·74	0·10	177·99	—

The results for the acids are in the following tables. c'' is the ionic concentration corresponding to the molecular concentration C, calculated as described in Part IX (J., 1934, 1104), two approximations being sufficient, except for tetrolic acid, where three were required. $K_{1\text{therm.}}$ is the thermodynamic or true dissociation constant, deduced from the equation $\log K_{1\text{therm.}} = \log K' - 1{\cdot}010c''^{0{\cdot}5}$, where K' is the dissociation constant computed from the corresponding degree of dissociation $\alpha' = \Lambda_c/\Lambda_e$. The values of $K_{1\text{class.}}$ are included for comparison with the data in the literature.

$C \times 10^4$.	Λ_c.	$K_{\text{class.}} \times 10^5$.	Λ_e.	$c'' \times 10^4$.	K'.	$K_{\text{therm.}} \times 10^5$.
		Acrylic acid (M = 72·03) (Λ_0 = 388·8).				
		Run 1. Cell *Q*.	κ = 0·805.			
1·508	174·28	5·494	366·88	0·6793	5·571	5·465
7·740	91·38	5·575	386·11	1·8303	5·668	5·493
13·49	71·60	5·597	385·77	2·5038	5·696	5·494
27·66	51·69	5·638	385·01	3·7135	5·759	5·506
43·29	42·40	5·659	384·44	4·7855	5·797	5·509
59·76	36·08	5·673	384·16	5·4248	5·818	5·499
82·99	30·85	5·677	383·62	6·6739	5·838	5·497
107·8	27·22	5·681	383·22	7·6570	5·954	5·502
		Run 2. Cell *R*.	κ = 0·817.			
4·292	117·01	5·561	386·57	1·2992	5·639	5·492
10·47	80·12	5·600	386·08	2·1726	5·689	5·502
20·02	59·98	5·633	385·47	3·1152	5·740	5·509
34·37	46·75	5·648	384·76	4·1763	5·776	5·508
51·93	38·61	5·686	384·18	5·2190	5·831	5·530
71·67	33·13	5·688	383·74	6·1876	5·847	5·518
92·30	29·32	5·703	383·38	7·0589	5·846	5·496
					Mean	5·501

trans-*Crotonic acid* ($M = 86{\cdot}05$) ($\Lambda_0 = 381{\cdot}8$).

Run 1. Cell *Q*. $\kappa = 0{\cdot}783$.

$C \times 10^4$.	Λ_c.	$K_{class.} \times 10^5$. ($\times 10^5$).	Λ_e.	$c'' \times 10^4$.	K'.	$K_{therm.} \times 10^5$. ($\times 10^5$).
1·375	122·19	2·061	382·30	0·4395	2·065	2·033
5·672	66·57	2·079	382·29	0·9877	2·083	2·035
11·32	48·55	2·088	382·28	1·4352	2·092	2·034
22·18	35·43	2·096	382·27	2·0558	2·100	2·031
41·97	26·18	2·110	382·25	2·8749	2·114	2·032
55·99	22·80	2·114	382·24	3·3393	2·118	2·030
76·23	19·64	2·117	382·19	3·9172	2·122	2·027
98·39	17·36	2·122	382·16	4·4700	2·127	2·026

Run 2. Cell *R*. $\kappa = 0{\cdot}764$.

$C \times 10^4$.	Λ_c.	$K_{class.} \times 10^5$.	Λ_e.	$c'' \times 10^4$.	K'.	$K_{therm.} \times 10^5$.
8·052	56·61	2·085	382·29	1·1966	2·089	2·036
20·29	36·89	2·091	382·28	2·0545	2·095	2·026
34·47	28·75	2·105	382·26	2·5923	2·109	2·031
59·60	22·10	2·111	382·24	3·4459	2·115	2·025
71·07	19·66	2·118	382·21	3·6557	2·122	2·030
93·30	17·82	2·123	382·17	4·3504	2·128	2·027
					Mean	2·030

ββ-*Dimethylacrylic acid* ($M = 100{\cdot}06$) ($\Lambda_0 = 382{\cdot}6$).

Run 1. Cell *R*. $\kappa = 0{\cdot}822$.

$C \times 10^4$.	Λ_c.	$K_{class.}$ ($\times 10^6$).	Λ_e.	$c'' \times 10^4$.	K'.	$K_{therm.}$ ($\times 10^6$).
1·001	93·89	(7·984)	381·13	0·2465	8·057	(7·965)
4·914	44·87	7·633	380·85	0·5861	7·738	7·601
13·82	27·51	7·697	380·64	0·9964	7·780	7·601
26·54	20·06	7·699	380·49	1·3991	7·787	7·576
46·20	15·32	7·715	380·34	1·8608	7·810	7·560
60·42	13·44	7·721	380·24	2·1348	7·823	7·561
77·52	11·88	7·728	380·16	2·4247	7·830	7·551
98·44	10·58	7·735	380·07	2·7392	7·840	7·561

Run 2. Cell *Q*. $\kappa = 0{\cdot}818$.

$C \times 10^4$.	Λ_c.	$K_{class.} \times 10^6$.	Λ_e.	$c'' \times 10^4$.	K'.	$K_{therm.} \times 10^6$.
2·319	63·41	7·636	380·98	0·3878	7·708	7·597
7·517	36·75	7·673	380·76	0·7255	7·751	7·598
18·74	23·74	7·693	380·58	1·1690	7·777	7·584
34·78	17·59	7·706	380·41	1·6082	7·798	7·571
55·42	14·01	7·713	380·28	2·0417	7·810	7·557
73·73	12·18	7·717	380·17	2·3622	7·818	7·543
85·68	11·32	7·729	380·13	2·5515	7·825	7·539
95·03	10·76	7·733	380·08	2·6903	7·838	7·544
					Mean	7·569

Furoic acid ($M = 112{\cdot}03$) ($\Lambda_0 = 383{\cdot}0$).

Run 1. Cell *Q*. $\kappa = 0{\cdot}845$.

$C \times 10^4$.	Λ_c.	$K_{class.}$.	Λ_e.	$c'' \times 10^4$.	K'.	$K_{therm.}$.
1·386	326·61	6·849	382·51	1·1304	6·918	6·748
5·908	247·79	7·005	382·26	3·8292	7·056	6·742
11·99	202·25	7·084	381·90	6·3486	7·148	6·741
24·43	158·87	7·185	381·27	10·1790	7·272	6·751
40·94	130·96	7·274	380·50	15·0917	7·430	6·809
53·83	117·74	7·344	379·86	16·6844	7·495	6·806
78·17	100·96	7·391	379·19	20·9267	7·568	6·805
99·25	91·46	7·436	378·71	24·2483	7·615	6·807

Run 2. Cell *R*. $\kappa = 0{\cdot}840$.

$C \times 10^4$.	Λ_c.	$K_{class.}$.	Λ_e.	$c'' \times 10^4$.	K'.	$K_{therm.}$.
3·243	284·81	6·997	382·27	2·4162	7·062	6·811
8·262	226·34	7·055	382·12	4·8938	7·110	6·754
15·71	184·45	7·141	381·71	7·6325	7·213	6·764
26·15	155·18	7·217	381·19	10·6455	7·310	6·776
38·29	134·25	7·243	380·65	13·5044	7·353	6·751
50·12	120·97	7·309	380·19	15·9474	7·442	6·767
71·79	104·56	7·360	379·37	19·9864	7·528	6·787
90·45	95·13	7·424	378·75	23·9539	7·620	6·801
					Mean	6·776

***Tetrolic acid* (M = 84·03) (Λ_0 = 387·2).**

$C \times 10^4$.	Λ_c.	$K_{class.} \times 10^5$. (× 10³).	Λ_e.	$c'' \times 10^4$. $c''' \times 10^4$.	K'.	$K_{therm.} \times 10^5$. (× 10³).
			Run 1. Cell *R*. κ = 0·845.			
1·265	360·16	(1·566)	386·77	1·1782	1·592	(1·552)
9·577	295·13	2·340	386·38	6·9861	2·367	2·226
12·20	281·08	2·346	386·19	8·4802	2·374	2·219
25·44	234·21	2·356	385·02	15·4761	2·437	2·194
40·96	204·30	2·412	383·99	21·7931	2·479	2·223
61·76	178·78	2·446	382·93	29·5089	2·526	2·236
74·72	167·33	2·452	382·26	33·7025	2·546	2·224
94·21	154·08	2·478	381·62	39·5615	2·577	2·246
			Run 2. Cell *Q*. κ = 0·821.			
3·926	337·45	2·321	386·75	3·4414	2·344	2·245
15·21	267·59	2·352	385·87	10·5477	2·387	2·213
22·15	244·06	2·380	385·27	14·0315	2·425	2·223
33·46	217·37	2·414	384·35	18·9234	2·464	2·226
54·56	186·65	2·448	383·30	26·5683	2·522	2·237
67·67	173·31	2·454	382·73	30·6427	2·536	2·230
84·50	160·55	2·482	382·07	35·5078	2·574	2·240
100·1	150·99	2·495	381·56	39·6114	2·594	2·241
						Mean 2·228

***trans-Glutaconic acid* (M = 130·05) (Λ_0 = 378·2).**

$C \times 10^4$.	Λ_c.	$K_{1class.} \times 10^4$.	Λ_e.	$c'' \times 10^4$.	K'.	$K_{2therm.} \times 10^4$.
			Run 1. Cell *Q*. κ = 0·615.			
1·220	285·05	2·809	—	—	—	—
8·516	141·13	1·891	—	—	—	—
13·61	116·32	1·856	—	—	—	—
21·39	95·09	1·805	376·41	5·4036	1·826	(1·730)
56·19	62·00	1·806	375·67	9·2737	1·833	1·706
71·46	55·75	1·819	375·43	10·6113	1·848	1·713
99·67	47·91	1·832	374·99	12·7342	1·865	1·717
			Run 2. Cell *R*. κ = 0·632.			
3·980	202·54	2·458	—	—	—	—
14·75	110·92	1·795	—	—	—	—
30·12	81·77	1·796	376·19	6·5470	1·818	1·713
48·05	66·45	1·800	375·82	8·4959	1·825	1·705
64·18	58·39	1·809	375·53	9·9791	1·837	1·706
77·12	53·81	1·820	375·36	11·0556	1·850	1·712
87·48	50·87	1·829	375·21	11·8604	1·860	1·717
						Mean 1·711

The values of the equivalent conductivities at round concentrations were interpolated from the conductivity–concentration graph drawn with a flexible spline.

Conductivities at Round Concentrations.
Acids.

$C \times 10^4$.	Acrylic.	*trans*-Crotonic.	$\beta\beta$-Dimethyl-acrylic.	Tetrolic.	Furoic.	*trans*-Glutaconic (μ).
1	—	—	90·0	376·0	335·0	290·0
2	155·0	86·1	—	—	—	—
5	108·3	67·2	$43{\cdot}3_2$	322·0	267·0	170·5
10	81·6	52·2	31·8	289·6	212·0	129·0
20	60·5	36·8	22·8	249·7	171·3	98·31
30	49·8	31·0	19·0	224·5	147·3	81·78
40	43·8	26·9	16·5	206·6	131·4	71·62
50	39·7	23·8	14·7	192·4	119·8	65·03
60	35·7	21·7	$13{\cdot}2_5$	180·6	111·4	60·52
70	32·8	20·4	12·2	272·3	104·9	56·62
80	30·4	19·2	11·3	163·2	99·7	53·34
90	28·8	18·4	10·8	257·1	95·3	50·58
100	27·9	17·5	10·6	151·6	92·3	47·97

Sodium salts.

$C \times 10^4$.	Acrylate.	*trans*-Crotonate.	ββ-Dimethylacrylate.	Tetrolate.	Furoate.	*trans*-Glutaconate (μ).
5	86·18	83·86	81·23	88·32	83·83	202·70
10	84·17	83·53	80·42	87·88	83·26	198·33
20	81·66	82·86	79·20	87·23	82·27	191·75
30	80·04	82·30	78·53	86·46	81·52	186·60
40	78·87	81·78	77·96	85·85	80·94	184·50
50	77·96	81·30	77·45	85·33	80·48	182·30
60	77·27	80·83	76·95	84·86	80·07	180·75
70	76·71	80·41	76·54	84·46	79·78	179·80
80	76·26	80·02	76·19	84·14	79·48	179·05
90	75·75	79·64	75·87	83·83	79·23	178·40
100	75·19	79·27	75·59	83·30	79·02	177·90

Potentiometric Measurements.—The experimental details have already been described (for references, see this vol., p. 1108). Measurements were conducted in an electrically-controlled oil thermostat maintained at 25° ± 0·01° with the quinhydrone electrode. The results for monobasic acids were computed as described for phenylacetic acid (J., 1935, 913), and for glutaconic acid as detailed for fumaric acid (*Phil. Mag.*, 1936, 22, 797) (the potentiometric titration figures are incorporated in the table).

Acrylic acid.

Potentiometric titration of 100·00 *c.c. of* 0·01M-*acid with* 0·01037*M*-NaOH at 25°.

NaOH, c.c.	p_H.	$\mu \times 10^3$.	$K_{therm.} \times 10^5$.
0·00	3·105	—	—
10·00	3·457	—	—
20·00	3·710	1·923	5·56
25·00	3·819	2·225	5·55
30·00	3·915	2·515	5·57
35·00	4·013	2·785	5·50
40·00	4·105	3·042	5·47
45·00	4·19	3·283	5·54
50·00	4·274	3·509	5·53
55·00	4·358	3·724	5·57
60·00	4·453	3·924	5·53
65·00	4·548	4·111	5·55
70·00	4·663	4·291	5·42
75·00	4·783	4·459	5·42
80·00	4·959	—	—
90·00	5·589	—	—
		Mean	5·52

trans-*Crotonic acid.*

Potentiometric titration of 100·00 *c.c. of* 0·01M-*acid with* 0·00990*M*-NaOH *at* 25°.

NaOH, c.c.	p_H.	$\mu \times 10^3$.	$K_{therm.} \times 10^5$.
0·00	3·365	—	—
10·00	3·785	1·064	2·09
20·00	4·086	1·732	2·05
25·00	4·201	2·063	2·08
30·00	4·299	2·334	2·07
35·00	4·391	2·608	2·08
40·00	4·475	2·864	2·11
45·00	4·560	3·101	2·11
50·00	4·644	3·324	2·11
55·00	4·729	3·533	2·11
60·00	4·820	3·730	2·09
65·00	4·907	3·912	2·10
70·00	5·000	4·087	2·11
75·00	5·105	4·251	2·12
80·00	5·223	4·405	2·13
		Mean	2·10

ββ-Dimethylacrylic acid.

Potentiometric titration of 100·00 *c.c. of* 0·01M-*acid with* 0·00980*M*-NaOH *at* 25°.

NaOH, c.c.	p_H.	$\mu \times 10^3$.	$K_{therm.} \times 10^6$.
0·00	3·600	—	—
10·00	4·174	—	—
20·00	4·496	1·666	7·61
25·00	4·614	1·985	7·63
30·00	4·718	2·280	7·64
35·00	4·826	2·616	7·60
40·00	4·905	2·813	7·61
45·00	4·989	3·051	7·63
50·00	5·074	3·275	7·63
55·00	5·157	3·484	7·65
60·00	5·245	3·682	7·61
65·00	5·333	3·865	7·62
70·00	5·428	4·039	7·61
75·00	5·533	4·204	7·58
80·00	5·655	4·357	(7·48)
90·00	5·971	—	—
100·00	6·969	—	—
		Mean	7·62

Tetrolic acid.

Potentiometric titration of 100·00 *c.c. of* 0·01M-*acid with* 0·00989*M*-NaOH *at* 25°.

NaOH, c.c.	p_H.	$\mu \times 10^3$.	$K_{therm.} \times 10^3$.
0·00	2·408	—	—
10·00	2·508	—	—
20·00	2·605	4·131	(2·27)
25·00	2·660	4·166	2·21
30·00	2·708	4·241	2·23
35·00	2·760	4·302	2·23
40·00	2·813	4·364	2·24
45·00	2·870	4·418	2·23
50·00	2·929	4·476	2·23
55·00	2·990	4·534	2·24
60·00	3·057	4·586	2·23
65·00	3·132	4·633	2·22
70·00	3·213	4·684	2·22
75·00	3·308	4·732	2·19
80·00	3·416	4·779	2·19
90·00	3·756	—	—
100·00	5·337	—	—
		Mean	2·22

Furoic acid.

Potentiometric titration of 100·00 *c.c. of* 0·01M-*acid with* 0·00961*M*-NaOH *at* 25°.

NaOH, c.c.	p_H.	$\mu \times 10^3$.	$K_{therm.} \times 10^4$.
0·00	2·644	—	—
10·00	2·743	2·683	(7·13)
20·00	2·871	2·948	6·91
25·00	2·925	3·110	7·08
30·00	2·990	3·242	6·98
35·00	3·051	3·360	6·94
40·00	3·111	3·520	7·01
45·00	3·176	3·649	6·99
50·00	3·237	3·784	7·09
55·00	3·311	3·898	6·93
60·00	3·379	4·022	7·00
65·00	3·455	4·136	6·99
70·00	3·540	4·246	6·93
75·00	3·624	4·356	7·05
80·00	3·726	4·459	7·07
90·00	4·000	—	—
100·00	4·452	—	—
		Mean	7·00

trans-Glutaconic acid.

Potentiometric titration of 100·00 *c.c. of* 0·005M*-acid with* 0·01170*M*-NaOH *at* 25°. *Calculation of dissociation constants.*

Pairs of points used. NaOH, c.c.	p_H.	$\mu \times 10^3$.	$K_{1\,class.} \times 10^4$.	$K_{1\,therm.} \times 10^4$.	$K_{2\,class.} \times 10^6$.	$K_{2\,therm.} \times 10^6$.
0·00	3·406	—	—	—	—	—
45·00	4·425	—	—	—	—	—
10·00	3·377	—	—	—	—	—
50·00	4·575	—	—	—	—	—
15·00	3·548	1·825	1·82	1·73	—	—
55·00	4·724	5·146	—	—	11·42	8·67
17·50	3·623	2·015	1·83	1·74	—	—
57·50	4·807	5·400	—	—	11·27	8·64
20·00	3·712	2·232	1·76	1·66	—	—
62·50	4·978	6·026	—	—	10·92	8·33
22·50	3·775	2·390	1·81	1·71	—	—
65·00	5·052	6·230	—	—	11·14	8·46
25·00	3·846	2·582	1·81	1·71	—	—
60·00	4·885	5·750	—	—	11·18	8·58
27·50	3·920	2·732	1·80	1·70	—	—
67·50	5·146	6·511	—	—	11·01	8·31
30·00	4·000	2·970	1·77	1·66	—	—
70·00	5·240	6·687	—	—	11·07	8·32
32·50	4·068	3·189	1·79	1·68	—	—
72·50	5·352	6·931	—	—	10·85	8·92
35·00	4·140	3·140	1·82	1·70	—	—
75·00	5·481	7·175	—	—	10·75	8·00
40·00	4·269	—	—	—	—	—
80·00	5·701	—	—	—	—	—
			Mean	1·70	Mean	8·38

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337. *The Conductivity and* p_H *Values of Calcium Hydroxide Solutions at* 25°.

By F. M. Lea *and* G. E. Bessey.

Existing data on the conductivity of calcium hydroxide solutions at 25° show discrepancies. New data are given which confirm certain of the previously published results. Values of p_H for calcium hydroxide solutions at 25° are also given and compared with the only other available data, those of Flint and Wells at 30°.

The solutions were prepared by igniting pure calcium carbonate (British Drug Houses, A.R.) at 1000° to constant weight, slaking the product in conductivity water ($\kappa = 1 - 2 \times 10^{-6}$), and keeping the mixture with intermittent shaking for several days. The solution was decanted, and the extraction repeated several times to remove any alkali. The saturated solution was diluted in the conductivity cell or electrode vessel with conductivity water to the concentration required, the necessary precautions being taken to avoid contamination by atmospheric carbon dioxide. In most cases the calcium hydroxide content was estimated gravimetrically by precipitation as oxalate and ignition to carbonate at 550° ± 20°. This method has been used by the authors for some years, since it avoids the difficulties inherent in the weighing of calcium oxide (cf. Bassett, J., **1934**, 1270; Willard and Boldyreff, *J. Amer. Chem. Soc.*, **1930**, **52**, 1888). The estimation was carried out on 50 c.c. of the solution from the conductivity cell and, with this volume, the precision is not greater than 0·3% even with the more concentrated solutions. The use of larger bulk solutions from which the conductivity cell is filled, or the preparation of solutions from known weights of solid calcium oxide, is open to other objections.

The conductivity measurements were carried out at 25° ± 0·1° in hard-glass cells, a Cambridge reed hummer (frequency 1100 cycles) and a bridge made up of a Cambridge low-induction resistance box and inductionless ratio arms being used. The *E.M.F.* measurements at 25° ±

0·1° were made on a Cambridge potentiometer reading to 0·0001 volt, a 0·1*N*- or *N*-calomel electrode and a saturated potassium chloride bridge being used. For the hydrogen cell both palladised gold and lightly platinised platinum electrodes were used and found equally satisfactory. The observed *E.M.F.* values were corrected in the usual manner for barometric pressure. The measurements recorded were made during several years and in the earlier ones the 0·1*N*-calomel electrode was used as standard and in the later ones the *N*-calomel electrode.

Conductivity Data.—The conductivity results are in Table I. The limiting factor determining their accuracy is the precision with which the concentration of the calcium hydroxide solution can be estimated. Previous measurements of the conductivity of calcium hydroxide solutions at 25° have been made by Ostwald (data recalculated by Kohlrausch) (Mellor, " Treatise on Inorganic and Theoretical Chemistry," **1923**, **3**, 684), Noda and Miyoshi (*J. Soc. Chem. Ind. Japan*, 1932, **35**, 317B), Grieve, Gurd, and Maass (*Canadian J. Res.*, 1933, **8**, 577), and Larocque and Maass (*ibid.*, 1935, **13**, 276). Comparison with the results of these authors was made by applying the equation $\Lambda = \Lambda_\infty - ac^{\frac{1}{3}}$ to the present data and calculating the Λ values corresponding to the values of c used by them. The cubic equation fits the present data, the constants being derived by the method of least squares, with mean deviations of about 0·5%. The constant a = 162·1 and Λ_∞ = 258, c being expressed as gram-equivalents per litre. No great significance can be attached to the Λ_∞ value derived by this method. The formula $\Lambda = \Lambda_\infty - 222{\cdot}1c^{\frac{1}{2}}$ fits the data equally well, but gives the value Λ_∞ = 246. The value for Λ_∞ derived from ionic mobility data at 25° (" International Critical Tables," VI, 270) is 256. Interpolated values for the conductivity at uniform intervals of concentration, derived from the mean of those given by the square and cubic formulæ, are in Table II.

TABLE I.

Specific Conductivity of Calcium Hydroxide Solutions at 25°.

Conc., g. CaO per l.	1·230	1·202	1·021	0·960	0·747	0·652	0·561	0·466	0·373	0·300	0·224	0·112
$\kappa \times 10^3$	8·84	8·61	7·37	6·98	5·56	4·91	4·29	3·58	2·95	2·38	1·82	0·93

TABLE II.

Interpolated Specific Conductivities of Calcium Hydroxide Solutions at 25°.

Conc., g. CaO per l.	1·2	1·0	0·8	0·6	0·4	0·2
$\kappa \times 10^3$	8·60	7·30	5·96	4·57	3·13	1·62

The older data of Ostwald compared in this way are 1—2% below the present conductivity values, and those of Noda and Miyoshi vary from 0·5% lower to 1% higher with an average summed discrepancy of 0·6%. Grieve, Gurd, and Maass give only the conductivity of a saturated calcium hydroxide solution at 25°, but the actual concentration was not determined analytically. In view of the considerable extent to which the concentration of an apparently saturated lime solution may vary with the method of preparation (Bassett, *loc. cit.*) no comparison of the conductivity value can be made. From data, however, at 0° to 30° conductivity values at 25° may be interpolated at two concentrations (0·737, 0·536 g. CaO per l.); the values obtained are 2—3% below both the present data and that of Noda and Miyoshi. The later data, of Larocque and Maass, by a similar method of interpolation, yield values from 1 to 1·5% below the present data over the concentration range 0·56—0·84 g. CaO per l., but show larger differences at higher and at lower concentrations. The solubility of calcium oxide at 25° was given by Grieve, Gurd, and Maass as 1·25 g. per l. and later corrected by Larocque and Maass to 1·28. These workers used calcium oxide for the preparation of the saturated solution. The solubility so obtained is high compared with that given by crystalline calcium hydroxide, for which a value of 1·12 g. CaO per l. has been found in the present work, in good agreement with Bassett's value of 1·13.

Values of p_H.—Measurements were made on the cell :

$$\underset{E_x}{\text{Pt }(H_2)|}Ca(OH)_2\underset{e_1}{|}\text{Sat. KCl}\underset{e_2}{|}0{\cdot}1N\text{-KCl or }N\text{-KCl }Hg_2Cl_2\underset{E_s}{|}Hg$$

In order to determine E_x it is necessary to allot values to e_1, e_2, and E_s. Flint and Wells (*Bur. Standards J. Res.*, **1933**, **11**, **163**), in determining the activities of calcium hydroxide solutions at 30° by measurements of the cell

$$Pt(H_2)|Ca(OH)_2|Sat.KCl\ Hg_2Cl_2|Hg,$$

calculated the value of e_1 from the Henderson formulæ in the form :

$$e = \frac{RT}{F}\frac{(\Lambda cf)_{KCl}(n_K - n_{Cl}) + (\Lambda c)_{Ca(OH)_2}(n_{OH} - \frac{1}{2}n_{\frac{1}{2}Ca})}{(\Lambda cf)_{KCl} - (\Lambda c)_{Ca(OH)_2}}\log\frac{(\Lambda cf)_{KCl}}{(\Lambda c)_{Ca(OH)_2}} \quad . \quad . \quad (1)$$

The value used for the transport number of the potassium ion (0·473) was that found in saturated solutions. Guggenheim and Schindler (*J. Physical Chem.*, **1934**, **38**, **533**), however, have recommended that, as most of the contribution to the diffusion potential comes from the more dilute end of the transition layer, the value $n_K = 0·490$, which is constant for potassium chloride solutions up to 0·5*N*, should be used. This gives values for the diffusion potential e_1 only about one third of those calculated by Flint and Wells. For the present calculations the value $n_K = 0·490$ has been used. The activity coefficient for $Ca(OH)_2$ has been assumed unity, and $n_{\frac{1}{2}Ca} = 0·214$, similarly to Flint and Wells. The data for potassium chloride used in the calculations were as follows :

	Sat. KCl.	*N*-KCl.	0·1*N*-KCl.		Sat. KCl.	*N*-KCl.	0·1*N*-KCl.
Λ	95*	112	129·0	n_K	0·49	0·49	0·49
f	0·57	0·61	0·78	*c*	4·18	1·0	0·1

* Obtained by extrapolation of data up to 4*N*.

If the activity coefficient for potassium chloride is omitted from equation (1), the calculated diffusion potential $Ca(OH)_2$|sat.KCl becomes about 0·0005 volt more negative for the most dilute calcium hydroxide solution and 0·001 volt more negative for the most concentrated.

The value of E_s adopted for the 0·1*N*-calomel electrode was 0·3337 volt at 25° as recommended by Guggenheim and Schindler (*loc. cit.*). This is a different basis from that used by Flint and Wells, who took the value 0·2383 volt for the saturated calomel electrode at 30°.* The value taken for the *N*-calomel electrode was 0·2799 volt, the potential difference between the *N*- and the 0·1*N*-calomel electrode being taken as 0·0528 volt and the diffusion potential *N*-KCl|0·1*N*-KCl calculated from formula (1) as 0·0010 volt.

The data obtained in the present investigation are in Table III.

TABLE III.

p_H *of Calcium Hydroxide Solutions.*

CaO, g. per l.	CaO, g.-equiv. per l. (*c*).	Measured cell *E.M.F.* Against 0·1*N*-calomel.	Against *N*-calomel.	e_1.	e_2.	E_x.	p_H.
0·064	0·00228	—	− 0·9480	− 0·0028	+ 0·0006	− 0·6659	11·27
0·065	0·00232	—	− 0·9490	− 0·0028	+ 0·0006	− 0·6669	11·28
0·122	0·00435	− 1·0165	—	− 0·0023	+ 0·0016	− 0·6821	11·54
0·164	0·00585	—	− 0·9705	− 0·0021	+ 0·0006	− 0·6891	11·66
0·271	0·00970	− 1·0365	—	− 0·0016	+ 0·0016	− 0·7028	11·89
0·462	0·0165	− 1·0482	—	− 0·0010	+ 0·0016	− 0·7151	12·10
0·680	0·0243	—	− 1·0065	− 0·0005	+ 0·0006	− 0·7267	12·29
0·710	0·0254	—	− 1·0076	− 0·0005	+ 0·0006	− 0·7279	12·31
0·975	0·0348	− 1·0670	—	+ 0·0001	+ 0·0016	− 0·7350	12·44
1·027	0·0367	—	− 1·0166	+ 0·0002	+ 0·0006	− 0·7375	12·47
1·160	0·0414	—	− 1·0195	+ 0·0005	+ 0·0006	− 0·7407	12·53

The p_H values shown in the last column of Table III would be altered by as much as 0·1 unit by the adoption of other values still commonly used for the 0·1*N*-calomel electrode and the various diffusion potentials.

The p_H values obtained by Wells at 30° are 0·17 unit below the present values at 25° at $c = 0·003$, and 0·20 unit lower in the solutions of highest concentration. This large

* Derived from the value 0·3372 at 30° for the 0·1*N*-calomel electrode, 0·0942 for the potential difference directly measured between the 0·1*N*- and the saturated calomel electrode, and 0·0046 calculated diffusion potential using the value $n_K = 0·473$.

variation is due in part to the difference in the values adopted for the standard electrodes, which, as far as calculation can be made, affects the p_H by about 0·02, and to a larger extent to the different methods used for calculating the diffusion potentials. The use of the diffusion potential values adopted in the present work would raise the p_H values of Flint and Wells by about 0·1 unit at the lowest concentrations and 0·05 unit at the highest.

BUILDING RESEARCH STATION, GARSTON, HERTS. [*Received, August 17th, 1937.*]

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338. *The Acetylation and Methylation of Agar-agar and the Isolation of 2 : 4 : 6-Trimethyl* α-d-*Galactose by Hydrolysis.*

By E. G. V. PERCIVAL and J. CARGILL SOMERVILLE.

Methods for the acetylation and methylation of agar are described. Hydrolysis of methylated agar with dilute sulphuric acid yields (A) methyl lævulate, (B) a 2 : 4 : 6-trimethyl methylgalactoside, from which the previously unknown 2 : 4 : 6-trimethyl α-galactose has been isolated, and (C) a fraction which gives strong ketose reactions—as does agar itself on mild hydrolysis—and is considered to be a dimethyl methylketoside.

β-*d*-Galactopyranose units linked either directly together by positions 1 and 3 or by means of an intermediary ketose residue appear to be chiefly concerned in the structure of this complex polysaccharide.

PERCIVAL and SIM (*Nature*, 1936, **137**, 997) showed that agar could be acetylated to yield a chloroform-soluble agar acetate which on deacetylation regenerated a substance identical with the original polysaccharide in its ability to form a gel. This was regarded as evidence that no substantial degradation had taken place during acetylation. Later Percival, Munro, and Somerville (*ibid.*, 1937, **139**, 512) described some preliminary results of the hydrolysis of the methylated derivative obtained from the acetate. The details of this work and also the progress made in the identification of the acid portion of the hydrolysis product of agar are now described.

Agar acetate was obtained either as a tough colourless glass from chloroform solution or as a white powder by precipitation from solution by light petroleum. Further acetylation had no effect on its properties, and almost ash-free agar was obtained from it on deacetylation. Deacetylation and methylation yielded a product, soluble in chloroform and acetone, unchanged on further methylation. Fractional precipitation from chloroform solution gave four identical fractions, indicating the homogeneous character of the product.

Hydrolysis with 6% sulphuric acid was complete in four hours, the solution acquiring a positive rotation; at the same time methyl alcohol (3—4%) was evolved, and a brown resin (3%) deposited. No furfural derivatives could be detected. After neutralisation with barium carbonate an estimation of barium in the hydrolytic product gave 6·7%. The barium salt, however, obtained by precipitation with alcohol contained no methoxyl residue. Owing to the solubility of this barium salt it was impossible to separate it quantitatively from the sugars (*ca.* 75%) formed on hydrolysis; therefore glucoside formation and esterification were carried out on the entire hydrolytic product. Distillation in a high vacuum yielded: (A) an optically inactive, mobile ester (16%), (B) a crystalline trimethyl methylgalactoside (65%), and (C) a syrup (14%). The yield of (B) thus isolated from methylated agar was *ca.* 50% of the starting material, and by the hydrolysis of methylated agar with methyl-alcoholic hydrogen chloride a yield of *ca.* 60% was obtained. Assuming that methylated agar, as appears likely, is a true derivative of agar, it follows from this that the polysaccharide is composed of galactose residues to the extent of at least 55%, whereas previous authors (*e.g.*, Lüdtke, *Biochem. Z.*, 1929, **212**, 419) were able to detect only 30—40%.

From its physical properties, analytical composition, and comparison of the melting points and mixed melting points of the 2 : 4-dinitrophenylhydrazone and *p-nitrophenylhydrazone* prepared from an authentic specimen, (A) proved to be methyl lævulate. There would seem to be no doubt, therefore, that the acid formerly regarded as a constituent of agar is lævulic acid arising from the decomposition of a fragment of the molecule. Lüdtke (*loc. cit.*) indeed isolated a small amount of lævulic acid from the hydrolysis products of agar itself. It is well known that this acid is more readily produced from ketohexoses than from aldohexoses, and under the experimental conditions employed it was found that galactose gave rise to less than 2% and the trimethyl galactose from (B) to none at all. The hydrolysis of methylated agar with methyl-alcoholic hydrogen chloride yielded scarcely any lævulic ester, fractions (B) and (C) being obtained as before. The application of the Seliwanoff reaction and Bredereck's test on hydrolysed agar, methyl agar, and fraction (C) gave positive indication of the presence of a ketose, and it is considered, therefore, that the lævulic acid is derived from that source. Takahashi and Shirawa (*J. Fac. Agr. Hokkaido Imp. Univer. Japan*, 1934, **35**, 101), in their investigation on agar hydrolysed in an autoclave at 130°, also found a substance giving a ketose reaction. The above ketose tests were negative with fractions (A) and (B).

The crystalline non-reducing substance (B), $C_{10}H_{20}O_6$, m. p. 64°, $[\alpha]_D^{17°}$ + 107° in water [the rotation, in conjunction with the rotation of the corresponding trimethyl galactose (+ 124°), indicating it in all probability to be a mixture of the α- and the β-form with a preponderance of the former], proved to be a 2 : 4 : 6-*trimethyl methylgalactoside*, this structure being assigned for the following reasons. (1) Complete methylation yielded almost quantitatively 2 : 3 : 4 : 6-tetramethyl galactose, identified by its crystalline anilide. This observation at once identified it as a derivative of galactose and excluded the possibility of substitution at position 5. (2) Hydrolysis yielded a crystalline trimethyl galactose, $C_9H_{18}O_6$, m. p. 104—105°, $[\alpha]_D^{17°}$ + 124° in water, which readily formed a crystalline *dimethyl galactose phenylosazone*, indicating the presence of a methoxyl group in position 2 of the trimethyl galactose. Oxidation with bromine water under conditions favourable to the production of a γ-lactone yielded a trimethyl δ-galactonolactone, $[\alpha]_D^{18°}$ + 150° in water, which fell rapidly on standing to an equilibrium value of + 50° in 16 hours. The probability that position 4 was occupied by a methoxyl residue was confirmed by the observation that at room temperature in contact with 1% methyl-alcoholic hydrogen chloride the crystalline trimethyl galactopyranoside was regenerated, no galactofuranosides being detected. It became clear, therefore, that positions 2 and 4 were occupied by methoxyl residues. The trimethyl galactose cannot therefore be the 2 : 3 : 6-trimethyl galactose of Haworth, Raistrick, and Stacey (*Biochem. J.*, 1935, **29**, 2668) and indeed the physical constants confirm this fact. (3) It remained to decide between 2 : 3 : 4- and 2 : 4 : 6-trimethyl galactose. The former derivative in the form of a syrup has been isolated by Challinor, Haworth, and Hirst (J., 1931, 258) from the aldobionic acid of gum arabic and by Onuki (*Chem. Zentr.*, 1933, II, 367) from stachyose. The properties of the sugar in question, the rotation of the lactone formed by oxidation, and the properties of its derivatives appear to exclude the possibility of identity. Unfortunately we could not obtain a crystalline phenylhydrazide for comparison, but a crystalline *amide*, m. p. 167°, $[\alpha]_D^{20°}$ + 74°, was isolated. This, however, only serves to confirm the absence of identity with the 2 : 3 : 6-trimethyl galactose, since an amide of 2 : 3 : 4-trimethyl galactonolactone has not been described. Repeated attempts to obtain the trimethyl mucic acid which characterised the 2 : 3 : 4-trimethyl galactose of Challinor, Haworth, and Hirst (*loc. cit.*) failed, small yields of compounds of indefinite composition being obtained, of which the reducing properties seemed to indicate them to be derivatives of tartronic or mesoxalic acid. This result is in accordance with the assignment of the structure of 2 : 4 : 6-*trimethyl α-galactose* to the methylated galactose fragment.

It has not yet been found possible to identify the non-reducing fraction (C), which appears to be a dimethyl methylketoside (OMe, 39%). By Freudenberg and Soff's method (*Annalen*, 1932, **494**, 68), it was estimated that one methoxyl group was glycosidic. Treatment with 6% sulphuric acid under the conditions employed for the hydrolysis of methylated agar, followed by esterification, again gave rise to methyl lævulate together with

unchanged material, and this fact together with the strong ketose reactions exhibited seems to point to the presence of a ketose.

The fact that the rotations of acetylated and methylated agar are strongly negative, coupled with the isolation after hydrolysis of *d*-galactose derivatives, makes it clear that there is a preponderance of β-linkages in the molecule. If one assumed it to be composed entirely of β-galactopyranose units linked at positions 1 and 3, the most probable structures would be either a staggered zig-zag chain or a closed loop of six such units. If, however, the former alternative were correct, it would be expected that tetramethyl galactose or some other fully methylated sugar (cf. Haworth, Hirst, and Oliver, J., 1934, 1917) would be observed among the hydrolytic products, and although the possibility exists that some of the methyl lævulate may have been derived from a fully methylated ketose, no definite evidence for this, or for the presence of tetramethyl galactose, has yet been found and it will be necessary to hydrolyse large quantities of methylated agar before the point can be settled. Furthermore the isolation of what appears to be a dimethyl ketose in significant quantity makes it appear likely, unless the methylation of the ketose fragment is hindered in some way, that, if a chain of β-galactopyranose units is present, it may contain at points along its length ketose residues, and that loops (cf. Haworth, Hirst, and Isherwood, this vol., p. 577; Haworth, Hirst, and Oliver, *loc. cit.*) or cross linkages are present at these points. It is hoped that further work will enable progress to be made in this direction.

Pirie (*Biochem. J.*, 1936, **30**, 369) on the basis of the isolation of an aldehydo hepta-acetyl *dl*-galactose by the acetolysis of agar suggested that aldehydo galactose was present in the molecule. Freudenberg and Soff (*Ber.*, 1937, **70**, 264) have indicated, however, that aldehydo glucose hepta-acetate can be obtained from glucopyranose derivatives, so the substance isolated by Pirie may be a reversion product. The sulphuric ester grouping apparently present in agar (Neuberg and Ohle, *Biochem. Z.*, 1921, **125**, 311; Lüdtke, *loc. cit.*) is evidently hydrolysed during acetylation and methylation, since no sulphur can be detected in purified agar acetate or methylated agar. The properties of the material obtained on deacetylation do not seem to be affected by this and it may be that, as in the case of the phosphorus residue in starch (Baird, Haworth, and Hirst, J., 1935, 1201; Haworth, Hirst, and Waine, *ibid.*, p. 1299), the presence or absence of sulphuric ester residues has no very obvious effect on the properties of the polysaccharide, contrary to the view of Samec and Ssajevič (*Compt. rend.*, 1921, **173**, 1474).

Experimental.

Prepared Agar.—Powdered agar (B.D.H.) (100 g., ash 3·3%) was washed during 5 days five times with tap water (100 l.). The residue was treated with alcohol, washed with ether, and dried in the air [Found: C, 45·1; H, 6·2; ash, 2·0. Calc. for $(C_6H_{10}O_5)_x$: C, 44·4; H, 6·2%]. Treatment with *N*/20-hydrochloric acid at room temperature or with *N*/50-hydrochloric acid at 48° (1 minute), followed by the addition of alcohol and standing at 30° (½ hour), followed by washing and the further addition of alcohol, failed to reduce the ash content appreciably.

Acetylation of Agar.—Prepared agar (18 g. dry wt.) was shaken with pyridine (100 c.c.) for 1 hour, and a mixture of acetic anhydride (200 c.c.) and pyridine (100 c.c.) added. After heating at 95° for 6 hours and standing for 20 hours, the yellow solution was poured into ice-water (10 l.) with constant stirring. The product was washed free from acid, dried, and extracted with chloroform–acetone (1 : 1), the solution filtered, and the product precipitated by light petroleum and dried in a vacuum (22 g.). The agar acetate softened at 230° and had $[\alpha]_D^{18°}$ − 32·1° in chloroform (*c*, 0·5) (Found: C, 49·1; H, 5·8; CH_3·CO, 39·0. Calc. for $C_{12}H_{16}O_8$: C, 50·0; H, 5·6; CH_3·CO, 44·8%).

Methylated Agar.—Agar acetate (14 g.) in acetone (300 c.c.) was treated with methyl sulphate (70 c.c.) and sodium hydroxide (180 c.c., 30%) in $\frac{1}{10}$th portions every 10 minutes at 56°, followed by heating to 75° during 30 minutes. The white granular product (OMe, 27·7%), after being washed with hot water, was redissolved in acetone and remethylated as before (OMe, 28·3%). This operation was repeated twice more to yield a product, soluble in chloroform, precipitated by light petroleum as a white amorphous powder (10 g.), softening at 220°, $[\alpha]_D$ − 92° in chloroform (*c*, 0·6) (Found: OMe, 30·9%).

The Fractional Precipitation of Methylated Agar.—Methylated agar (5 g.), dissolved in chloro-

form (250 c.c.), was precipitated by successive additions of light petroleum (b. p. 60—80°) to yield four fractions :

(A) 0·9 g., $[\alpha]_D^{15°}$ − 92°	in chloroform (c, 0·4) ;		OMe, 31·0%.
(B) 1·2 g., $[\alpha]_D^{17°}$ − 92°	,, ,,	,,	OMe, 30·8%.
(C) 2·0 g., $[\alpha]_D^{17°}$ − 92°	,, ,,	,,	OMe, 30·9%.
(D) 0·6 g., $[\alpha]_D^{17°}$ − 92·5°	,, ,,	,,	OMe, 30·7%.

The Hydrolysis of Methylated Agar with Sulphuric Acid.—Methylated agar (8 g.) was heated at 95° with sulphuric acid (170 c.c., 6%). The substance gradually dissolved and a brown resin was deposited, which was filtered off (0·25 g. ; OMe, nil). A constant rotation ($[\alpha]_D^{20°}$ + 45°) was reached in 4 hours and the hydrolysis was continued during a further hour. The hydrolysate was neutralised with barium carbonate, and the filtered solution evaporated almost to dryness at 50°/10 mm. ; alcohol then precipitated a barium salt contaminated by reducing sugars. Solution in water and reprecipitation with alcohol gave a white powder (0·7 g. ; OMe, nil). The aqueous-alcoholic residues on evaporation to dryness gave a pale yellow, reducing syrup (6 g. ; OMe, 44%) which still contained some of the barium salt. By a modification of the method of Freudenberg and Soff (*loc. cit.*) it was estimated that methylated agar lost 3·5% of methyl alcohol during the hydrolysis.

Simultaneous Esterification and Glucoside Formation.—The neutralised hydrolytic product (7 g.) from another hydrolysis, which still contained the barium salt, was boiled with 5% methyl-alcoholic hydrogen chloride for 6 hours ; the solution was neutralised with silver carbonate, filtered, and evaporated at 40°/15 mm. to a non-reducing syrup (5·9 g.), which was fractionally distilled to yield the following fractions : (A) 0·98 g., bath temp. 90—100°/0·01 mm. ; (B) 3·8 g., bath temp. 150—160°/0·01 mm. ; (C) 0·85 g., bath temp. 180—190°/0·01 mm. ; residue, 0·4 g.

Identification of (A) *as methyl lævulate.* The colourless mobile liquid, which gave the iodoform reaction, had $n_D^{15°}$ 1·4250, $[\alpha]_D^{15°}$ ± 0° (Found : C, 54·8 ; H, 7·9 ; CO_2Me, 48·0. Calc. for $C_6H_{10}O_3$: C, 55·3 ; H, 7·8 ; CO_2Me, 45·3%). The 2 : 4-dinitrophenylhydrazone had m. p. 136°, alone or mixed with the 2 : 4-dinitrophenylhydrazone of methyl lævulate (m. p. 137°) (Found : N, 15·9. Calc. for $C_{12}H_{14}O_6N_4$: N, 16·2%). The *p*-nitrophenylhydrazone had m. p. 136°, alone or mixed with *methyl lævulate* p-*nitrophenylhydrazone* (m. p. 136°) (Found : C, 54·25 ; H, 5·65 ; N, 16·2. $C_{12}H_{15}O_4N_3$ requires C, 54·3 ; H, 5·7 ; N, 15·85%).

Identification of (B) *as 2 : 4 : 6-trimethyl methylgalactoside.* This fraction, which solidified completely during distillation, was recrystallised from light petroleum and had m. p. 62—64°, $[\alpha]_D^{15°}$ + 107° in water (c, 0·4) (Found : C, 50·0 ; H, 8·6 ; OMe, 51·1. $C_{10}H_{20}O_6$ requires C, 50·8 ; H, 8·5 ; OMe, 52·5%). *2 : 4 : 6-Trimethyl methylgalactoside* may also be isolated as a crystalline *hydrate*, m. p. 37°, $[\alpha]_D^{15°}$ + 101° in water (c, 0·4) (Found : C, 47·0 ; H, 8·6 ; OMe, 47·1. $C_{10}H_{20}O_6,H_2O$ requires C, 47·2 ; H, 8·7 ; OMe, 48·8%).

Complete Methylation and the Isolation of 2 : 3 : 4 : 6-Tetramethyl Galactose Anilide.—The crystalline galactoside (1 g.) was methylated in the usual way once with methyl sulphate and sodium hydroxide and once with silver oxide and methyl iodide. After extraction and distillation in a high vacuum the glucosidic residue was removed by heating for 2 hours with hydrochloric acid (7%), the fully methylated sugar being isolated and treated with aniline. Tetramethyl galactopyranose anilide was obtained (0·6 g.), m. p. 192°, unchanged on admixture with an authentic specimen.

The Isolation of 2 : 4 : 6-Trimethyl α-Galactose.—Hydrolysis of the trimethyl methylgalactoside (1 g.) during 2 hours with 7% hydrochloric acid, followed by neutralisation with silver carbonate and evaporation, gave a syrup, which crystallised on treatment with ether (0·7 g.). Recrystallisation from ether–light petroleum gave colourless needles, m. p. 104—105°, $[\alpha]_D^{15°}$ + 124° in water (c, 0·9), falling to + 93° (equilibrium value). This substance is shown below to be 2 : 4 : *6-trimethyl α-galactose* (Found : C, 48·2 ; H, 7·9 ; OMe, 40·0. $C_9H_{18}O_6$ requires C, 48·7 ; H, 8·1 ; OMe, 41·9%).

Osazone Formation and the Isolation of 4 : 6-Dimethyl Galactosazone.—The above sugar (0·5 g.) on treatment with phenylhydrazine (1 c.c.) and acetic acid (1 c.c.) and heating at 90° for 2 hours gave rise to yellow needles (0·4 g.), which were recrystallised from aqueous alcohol. They had m. p. 158°, $[\alpha]_D^{20°}$ − 25° in alcohol (c, 0·3) (Found : C, 62·3 ; H, 6·5 ; OMe, 14·9 ; N, 15·6. $C_{20}H_{26}O_4N_4$ requires C, 62·1 ; H, 6·8 ; OMe, 16·1 ; N, 14·5%).

Isolation of 2 : 4 : 6-Trimethyl δ-Galactonolactone and its Crystalline Amide.—The trimethyl galactose (1 g.) in water (14 c.c.) was treated with bromine (2 c.c.) for 26 hours at 35° and for 22 hours at 18°. Bromine was removed by aeration, the solution neutralised with silver carbonate, and the silver precipitated by hydrogen sulphide. Water was removed at 50°/15 mm. and

the yellow syrup (0·7 g.) was finally heated at 100°/0·01 mm. for 2 hours. It had $[\alpha]_D^{15°}$ + 152° in water (*c*, 0·2) (initial value); + 122° (45 minutes); + 112° (2 hours); + 90° (4 hours); + 50° (16 hours, constant value) (Found: OMe, 40·4; 0·165 g. required 14·9 c.c. of *N*/20-NaOH. Calc. for $C_9H_{16}O_6$: OMe, 42·4%; *N*/20-NaOH, 15·0 c.c.). A crystalline *amide* (0·3 g.) was formed by treating the lactone (0·3 g.) overnight with methyl-alcoholic ammonia, removing the solvent, and recrystallising the product from acetone; it formed lustrous plates, m. p. 167°, $[\alpha]_D^{12°}$ + 74° in water (*c*, 0·3) (Found: C, 46·0; H, 7·8; OMe, 37·6; N, 6·2. $C_9H_{19}O_6N$ requires C, 45·6; H, 8·1; OMe, 39·2; N, 5·9%).

Oxidation of the Lactone with Nitric Acid.—The lactone (2 g.) was oxidised with nitric acid under the conditions laid down by Challinor, Haworth, and Hirst (*loc. cit.*). No crystalline trimethyl mucic ester was obtained, but an ester (0·2 g.) resulted, which was distilled in a high vacuum and converted into an amide (0·05 g.) of zero rotation; this (Found: OMe, 1%) reduced ammoniacal silver nitrate, melted to a red liquid at 165—170°, and was probably impure tartronamide.

Regeneration of 2 : 4 : 6-*Trimethyl Methylgalactoside from* 2 : 4 : 6-*Trimethyl Galactose.*—The sugar in the form of a syrup (0·1 g.) was dissolved in 0·7% methyl-alcoholic hydrogen chloride (10 c.c.), and the change in rotation observed: $[\alpha]_D^{15°}$ + 52° (initial value); + 55° (13 hours); + 82° (26 hours); + 100° (70 hours, constant value). Neutralisation with silver carbonate and removal of solvent gave crystalline 2 : 4 : 6-trimethyl methylgalactoside in quantitative yield.

Examination of Fraction (C).—Redistillation at 190°/0·01 mm. gave a colourless non-reducing syrup, $[\alpha]_D^{15°}$ + 29° in chloroform (*c*, 0·4) [Found: OMe, 39·9; glucosidic OMe, 14·0 (Freudenberg and Soff, *loc. cit.*). $C_9H_{18}O_6$ requires OMe, 41·9%]. The syrup gave a strong Seliwanoff reaction with resorcinol, and the Bredereck reaction with ammonium molybdate. Positive tests were also secured with fructose and trimethyl methylfructofuranoside as controls, but negative results were obtained from galactose, glucose, 2 : 4 : 6-trimethyl galactose, and methyl lævulate. Agar too on mild hydrolysis gave the Bredereck reaction strongly. The syrupy ketoside was treated at 100° with 6% sulphuric acid (2 hours); esterification and distillation then gave more methyl lævulate (30%), indicating at least one probable source of this ester.

When the crystalline 2 : 4 : 6-trimethyl methylgalactoside was hydrolysed with sulphuric acid and submitted to glucoside formation and esterification exactly as for methylated agar, no methyl lævulate could be detected in the final product, so the trimethyl galactose must be discounted as a source of lævulic acid.

The Hydrolysis of Methylated Agar with Methyl-alcoholic Hydrogen Chloride.—Methylated agar (3 g.), dissolved in methyl-alcoholic hydrogen chloride (130 c.c., 5%), was heated at 80° for 6 hours until the rotation was constant. After neutralisation with silver carbonate and evaporation a syrup was isolated which on distillation gave crystalline 2 : 4 : 6-trimethyl methylgalactoside (1·9 g.) at 140—150°/0·03 mm. and a syrup (0·8 g.) at 190°/0·02 mm.; the latter appeared to be identical with the syrup (C), except that the rotation, $[\alpha]_D^{15°}$ + 13° in chloroform (*c*, 0·4), was somewhat lower. It was also found possible to hydrolyse methylated agar with 1% methyl-alcoholic hydrogen chloride.

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King's Buildings, University of Edinburgh. [*Received, July 29th,* 1937.]

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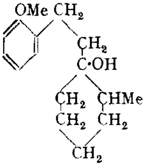
339. *Syntheses in the Phenanthrene Series. Part VIII.* 8-*Methoxy*-1-*methylphenanthrene.*

By Peter Hill, W. F. Short, and H. Stromberg.

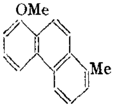
8-Methoxy-1-methylphenanthrene has been synthesised by the Bogert–Cook and by the Schroeter method. A novel case of ring fission of a hydroaromatic ring ketone by hydrobromic acid is described.

The first method employed for the synthesis of 8-*methoxy*-1-*methylphenanthrene* (II) involved the preparation of 1-β-o-*anisylethyl*-2-*methyl*cyclo*hexan*-1-*ol* (I) from the Grignard compound of β-o-*anisylethyl chloride* and 2-methyl*cyclo*hexanone. The unsaturated *com-*

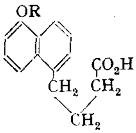
pound obtained by dehydration of this carbinol was treated with aluminium chloride, and the product *dehydrogenated with sulphur to yield* 8-methoxy-1-methylphenanthrene.



(I.)



(II.)



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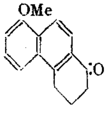

(IV.)

In the alternative synthesis we first prepared γ-5-methoxy-1-naphthylbutyric acid (III; R = Me) (Kon and Ruzicka, J., 1936, 191) by an improved method. Kon and Ruzicka reported that this acid was converted into " 1-keto-8-methoxy-1 : 2 : 3 : 4-tetrahydrophenanthrene," m. p. 137°, by the action of stannic chloride, but that an abnormal product, m. p. 88—89°, was produced when the corresponding acid chloride was treated with aluminium chloride. They state that the isomeride, m. p. 88—89°, did not react with semicarbazide and on demethylation gave a phenol $C_{14}H_{14}O_3$ (instead of $C_{14}H_{12}O_2$) which was not converted into the original methoxy-compound on methylation. By the action of phosphoric oxide on the acid we obtained the product, m. p. 88—89°, in good yield, and the same compound was produced in lower yield by the action of stannic chloride; no trace of the compound, m. p. 137°, could be isolated in either instance. We regard the isomeride of lower melting point as 1-*keto*-8-*methoxy*-1 : 2 : 3 : 4-*tetrahydrophenanthrene* (IV), since it formed a *semicarbazone* and a 2 : 4-*dinitrophenylhydrazone*. Demethylation of the methoxy-ketone with hydrobromic–acetic acid afforded the phenol $C_{14}H_{14}O_3$, m. p. 155°, described by Kon and Ruzicka and we find that the same compound is also produced by the demethylation of the acid (III; R = Me). It is therefore evident that the phenol is γ-5-*hydroxy*-1-*naphthylbutyric acid* (III; R = H) and that the action of hydrobromic–acetic acid on the methoxy-ketone (IV) causes ring fission as well as demethylation. There are many examples of the removal of a carbonyl side chain from aromatic compounds by the action of hydrobromic acid (Hill and Short, J., 1935, 1123), but there is no previous record of the fission of a hydroaromatic ring ketone by this reagent: 1-keto-7-methoxy-1 : 2 : 3 : 4-tetrahydrophenanthrene (Butenandt and Schramm, *Ber.*, 1935, **68**, 2083) and 6-methoxy-1-tetralone (Haberland, *Ber.*, 1936, **69**, 1380) undergo normal demethylation. Interaction between the cyclic ketone and methylmagnesium iodide afforded 8-*methoxy*-1-*methyl*-3 : 4-*dihydrophenanthrene*, dehydrogenation of which furnished 8-methoxy-1-methylphenanthrene (II) identical with that obtained by the first method.

Experimental.

The experimental methods were identical with those recorded in Parts I—VII and details are given only in those cases where modifications were necessary.

β-o-*Anisylethyl Chloride.*—Phenol (500 g.) was brominated at 170—175° by passing into it a mixture of nitrogen and bromine vapour (1 mol.) for 12 hours. The *o*- and the *p*-isomer were separated by fractionation and conversion of the former into the picrate (compare von Goedike, *Ber.*, 1893, **26**, 3042). In spite of this wasteful purification 24% of pure *o*-bromophenol was obtained. Holleman and Rinkes (*Rec. trav. chim.*, 1911, **30**, 48), who brominated phenol at 180° during 3 days, arrived at the *o* : *p* ratio 23 : 77 by thermal analysis. The higher *o* : *p* ratio obtained in our experiments is probably due to the greater speed of bromination (compare Hewitt, Kenner, and Silk, J., 1904, **85**, 1225; Skraup and Beifuss, *Ber.*, 1927, **60**, 1077). Methylation with methyl sulphate (1·3 mols.) and 10% aqueous sodium hydroxide (1·4 mols.) gave *o*-bromoanisole, b. p. 110°/20 mm., from which a 50% yield of β-*o*-anisylethyl alcohol, b. p. 126—127°/5 mm., was obtained by treating the Grignard reagent with ethylene oxide (compare Shoesmith and Connor, J., 1927, 2233; Bogert and Hamann, *Amer. Perf.*, 1930, **25**, 19). Thionyl chloride (1·2 mols.) was slowly added with mechanical stirring to a solution of the alcohol (1 mol.) in pyridine (1·5 mols.) cooled in a freezing mixture. The resulting pasty mass was warmed at 80—100° until no more gas

was evolved, and the product isolated in the usual manner. β-o-*Anisylethyl chloride*, b. p. 117—119°/8 mm., was obtained in 62% yield as an almost colourless oil (Found : Cl, 20·65. $C_9H_{11}OCl$ requires Cl, 20·8%).

1-β-o-*Anisylethyl-2-methyl*cyclo*hexan-1-ol* (I).—The Grignard compound of the preceding chloride and 2-methyl*cyclo*hexanone afforded the tertiary *alcohol* as a viscous liquid, b. p. 175—176°/7 mm. (Found : C, 77·1; H, 9·5. $C_{16}H_{24}O_2$ requires C, 77·4; H, 9·7%), and dehydration with potassium hydrogen sulphate yielded 1-β-o-*anisylethyl-2-methyl*cyclo*hexene*, b. p. 155—156°/6 mm. (Found : C, 83·45; H, 9·4. $C_{16}H_{22}O$ requires C, 83·5; H, 9·6%).

8-*Methoxy-1-methylphenanthrene*, obtained by treatment with aluminium chloride and dehydrogenation with sulphur, separated from 50% alcohol in small clustered needles, m. p. 96—97° (Found : C, 86·2; H, 6·2. $C_{16}H_{14}O$ requires C, 86·5; H, 6·3%). The *picrate* separated from alcohol in orange-red needles, m. p. 141·5—142·5° (Found : C, 58·0; H, 3·75. $C_{16}H_{14}O,C_6H_3O_7N_3$ requires C, 58·6; H, 3·8%). Demethylation of the methyl ether with hydrobromic–acetic acid furnished 8-*hydroxy-1-methylphenanthrene*, which separated from 40% methyl alcohol in white plates, m. p. 144—145° (Found : C, 86·2; H, 5·55. $C_{15}H_{12}O$ requires C, 86·5; H, 5·8%).

β-5-*Methoxy-1-naphthoylpropionic Acid*.—Bromination of α-nitronaphthalene at 95—100° with the theoretical quantity of bromine and a little iron powder furnished 1-bromo-5-nitronaphthalene in 56% yield (compare Ullmann and Consonno, *Ber.*, 1902, **35**, 2804). The best yield (65%) of 5-bromo-α-naphthylamine was obtained by reducing the nitro-compound with zinc and ammonium chloride as described by Fries and Köhler (*Ber.*, 1924, **57**, 504), and 5 : 5'-*dibromo-α-azoxynaphthalene*, m. p. 211·5—212° (decomp.), was isolated as a by-product (Found : C, 52·9; H, 2·9; N, 6·1; Br, 35·5. $C_{20}H_{12}ON_2Br_2$ requires C, 52·6; H, 2·6; N, 6·1; Br, 35·1%). Kon and Ruzicka (*loc. cit.*) obtained 5-bromo-α-naphthol in 20% yield by decomposing the diazonium salt with 9% sulphuric acid. The yield was raised to 41—44% by the following modification : A solution of the naphthylamine in acetic acid (14 mols.) was poured into 24% sulphuric acid (7·5 mols.) and diazotised at 5—7° with 17% aqueous sodium nitrite (1·3 mols.). Nitrous acid was destroyed by adding excess of urea, and the resulting clear solution added as rapidly as possible to boiling 40% sulphuric acid (13 mols.). The liquid was boiled for ½ hour, cooled, and filtered. The naphthol was extracted from the tar by boiling with dilute sodium hydroxide solution. Methylation with methyl sulphate (1·3 mols.) and 10% sodium hydroxide solution (1·4 mols.) at 30—70° afforded the methyl ether, b. p. 175°/10 mm., m. p. 67·5—68°, in 79% yield, and 9% of naphthol was recovered.

A Grignard solution prepared from 1-bromo-5-methoxynaphthalene (40 g.), benzene (100 c.c.), activated magnesium (4·16 g.), and ether (144 c.c.) was added during 1 hour to a boiling solution of succinic anhydride (17·3 g.) in benzene (346 c.c.). The yellow paste was boiled for an hour, cooled, and decomposed with dilute sulphuric acid, and the solvent layer extracted with dilute alkali. The oily acid solidified on trituration with methyl alcohol and recrystallisation from the same solvent afforded β-5-*methoxy-1-naphthoylpropionic acid*, m. p. 153·5—154° (Found : C, 69·8; H, 5·5. $C_{15}H_{14}O_4$ requires C, 69·8; H, 5·4%). The yield was 27% and another 3% was obtained by esterifying the acid in the mother-liquors and saponifying the fraction, b. p. 200—220°/1·5 mm.

γ-5-*Methoxy-1-naphthylbutyric Acid*.—Reduction of the keto-acid by Clemmensen's method, Martin's technique (*J. Amer. Chem. Soc.*, 1936, **58**, 1438) being used, gave a 51% yield of the butyric acid, which melted at 143° as recorded by Kon and Ruzicka (*loc. cit.*) (Found : C, 73·7; H, 6·7. Calc. for $C_{15}H_{16}O_3$: C, 73·8; H, 6·6%). Demethylation of the acid (0·5 g.) by boiling for 4½ hours with hydrobromic acid (28 c.c.; *d* 1·5) and acetic acid (22·5 c.c.) afforded γ-5-*hydroxy-1-naphthylbutyric acid*, which crystallised from dilute acetic acid in felted needles, m. p. 155—156° (Found : C, 72·95; H, 6·2. $C_{14}H_{14}O_3$ requires C, 73·05; H, 6·1%). Alcoholic ferric chloride produced first a dull red-green and then a bluish-violet coloration and remethylation afforded the methoxy-acid, m. p. and mixed m. p. 143°.

1-*Keto-8-methoxy-1 : 2 : 3 : 4-tetrahydrophenanthrene*.—This compound was obtained in *ca.* 40% yield from the acid and stannic chloride (Kon and Ruzicka, *loc. cit.*) and in better yield by the action of phosphoric oxide on the acid in benzene solution (compare J., 1936, 321). It separated from light petroleum (b. p. 60—80°) in plates, m. p. 88—89° (Found : C, 79·6; H, 6·3. $C_{15}H_{14}O_2$ requires C, 79·7; H, 6·2%). The 2 : 4-*dinitrophenylhydrazone* crystallised from benzene–ethyl acetate in crimson grains, m. p. 250—251° (decomp.) (Found : C, 61·9; H, 4·6; N, 14·0. $C_{21}H_{18}O_5N_4$ requires C, 62·1; H, 4·4; N, 13·8%). The ketone afforded a very sparingly soluble *semicarbazone*, m. p. 221° (decomp.) (Found : C, 68·1; H, 6·1; N, 14·7. $C_{16}H_{17}O_2N_3$ requires C, 67·8; H, 6·0; N, 14·8%), and when boiled with hydrobromic–acetic acid furnished γ-5-hydroxy-1-naphthylbutyric acid, m. p. and mixed m. p. 155—156°.

8-*Methoxy-1-methyl-3 : 4-dihydrophenanthrene*.—Interaction between the cyclic ketone and methylmagnesium iodide (3 mols.) afforded 8-*methoxy-1-methyl-3 : 4-dihydrophenanthrene*, which

separated from methyl alcohol in irregular plates, m. p. 104—105° (Found: C, 85·65; H, 7·5. $C_{16}H_{16}O$ requires C, 85·7; H, 7·1%). Much of the product was an oil, which doubtless consisted of a mixture of the dihydrophenanthrene with the corresponding tertiary alcohol. Dehydrogenation of this oil with palladium–charcoal afforded 8-methoxy-1-methylphenanthrene, isolated as the picrate, which was identical with that obtained in the first method, but the yield was poor.

Addendum: Professor L. F. Fieser has pointed out to us that β-4 : 8-dimethoxy-1-naphthoylpropionic acid, γ-4 : 8-dimethoxy-1-naphthylbutyric acid and its methyl ester, which were described as new compounds in Part VII (this vol., p. 937), had already been prepared by Fieser and Hershberg (*J. Amer. Chem. Soc.*, 1936, **58**, 2382). We regret that we had overlooked the priority of these authors. Our experiments were completed in January, 1936, but publication was delayed until the orientation experiments described in Part VII had been performed.

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340. *The Basic Strengths of Tertiary Amines, Phosphines, and Arsines.*

By W. CULE DAVIES and H. W. ADDIS.

The dissociation constants of a number of bases in solution in 30% or 50% ethyl alcohol have been computed from the results of potentiometric titrations with hydrochloric acid at 20° employing a glass electrode. The following are the principal results. (1) Phenyldimethylphosphine is a slightly stronger base than dimethylaniline, whereas phenyldimethylarsine is a very weak base. This is not the sequence expected from the results of measurements of the velocity of interaction between these bases and alkyl halides: phosphine > arsine > amine. (2) Phenyldiethylphosphine is a slightly stronger base than phenyldimethylphosphine, but diethylaniline is much stronger than dimethylaniline. These results should be compared with the feeble reactivity of diethylaniline towards alkyl halides. (3) Methyl substituents in the *o*-position of the phenyldialkyl bases increase the strength of the base. Thus dimethylmesidine was one of the strongest tertiary aromatic amines investigated. On the other hand such substituents diminish the reactivity of the base towards alkyl halides. (4) A linear relation exists between the p_K of dimethylaniline and its *p*-substituted derivatives and the logarithm of the velocity coefficient of the reaction between the amine and methyl iodide. (5) The effects of nuclear substituents are generally weaker in the phosphines than in the amines.

A NOTEWORTHY feature of the chemistry of the Group V*b* elements is the very feebly basic character of phosphine and arsine relative to ammonia. No comparisons have hitherto been made of the basic strengths of tertiary organic amines, phosphines, and arsines. In view of recent results, mentioned below, on the reactivities of such tertiary compounds, measurements have now been made of their dissociation constants. The reactivity of a tertiary phosphine towards alkyl halides is much greater than that of the corresponding arsine, which in turn is greater than that of the amine (Davies and Lewis, J., 1934, 1599; Davies, J., 1935, 462). Further, tertiary phosphines show considerable activity in combining with *p*-benzoquinone and carbon disulphide, whereas amines and arsines only possess this power to a small degree (Davies, J., 1935, 1786). The facile oxidation of tertiary phosphines compared with tertiary amines is another example of the high reactivity of tertiary phosphines. Attempts were made to connect this remarkable activity of the tertiary phosphine with its dipole moment, which is by far the largest in a series of corresponding tertiary organic compounds derived from the Group V*b* elements: the dipole moments of the hydrides are in the order $NH_3 > PH_3 > AsH_3$. A satisfactory explanation of this difference arising from the substitution of organic groups into ammonia and phosphine is still lacking.

The method adopted for the measurement of the dissociation constants was an electro-

metric titration at 20° of the base in solution in 30% or 50% alcohol with standard hydrochloric acid in the same solvent, a glass electrode being used, with a saturated potassium chloride–calomel half cell as reference electrode. The procedure was almost identical with that of Bennett, Brooks, and Glasstone (J., 1935, 1821). We have preferred, however, to give our results as $p_K = p_H + \log C_{salt}/C_{base}$, or, where $p_H < 4$, the form corrected for hydrolysis, $p_K = p_H + \log \{(C_{salt} - [H^{\cdot}])/(C_{base} + [H^{\cdot}])\}$, rather than make any assumptions as to the values of p_K for water in the aqueous alcohols.

Dissociation Constants of Bases at 20°.

	30% Alcohol.					50% Alcohol.				
Base.	G. base/ 100 c.c.	Normality of HCl.	Mean p_K.		Mean variation from mean p_K.	G. base/ 100 c.c.	Normality of HCl.	Mean p_K.		Mean variation from mean p_K.
Dimethylaniline	0·1211	0·02	4·71	4·76	± 0·06	0·2411	0·0501	4·21		± 0·015
	0·2422	0·04	4·81		0·02					
	0·2422	0·04	4·71		0·02					
	0·0605	0·005	4·79		0·02					
Dimethyl-*o*-toluidine	0·0676	0·01	5·42	5·42	0·02	0·0676	0·01	5·07		0·025
	0·0338	0·005	5·42		0·02					
Dimethyl-*m*-toluidine	0·0676	0·01	4·86	4·86	0·01	—	—	—		—
	0·0338	0·005	4·86		0·01					
Dimethyl-*p*-toluidine	0·0676	0·01	5·31	5·29	0·03	0·0676	0·005	4·77		0·02
	0·0338	0·005	5·26		0·03					
o-Methoxydimethylaniline	—	—	—		—	0·1511	0·02	5·49		0·01
p-Methoxydimethylaniline	0·1511	0·04	5·47	5·53	0	0·1511	0·02	5·16		0·02
	0·1511	0·02	5·56		0·06					
	0·3023	0·04	5·55		0·03					
p-Ethoxydimethylaniline	0·1652	0·02	5·59	5·59	0·02	—	—	—		—
	0·3303	0·04	5·59		0·02					
p-Nitrosodimethylaniline	—	—	—		—	0·0300	0·002	3·52		0·05
p-Fluorodimethylaniline	0·0348	0·005	4·49	4·49	0·02	0·0695	0·01	4·01		0·05
	0·0695	0·01	4·49		0·015					
p-Chlorodimethylaniline	0·0311	0·005	3·80		0·04	0·0778	0·01	3·45	3·33	0·03
						0·0389	0·005	3·21		0·02
p-Bromodimethylaniline	—	—	—		—	0·0500	0·005	2·82		0·02
p-Iododimethylaniline	—	—	—		—	0·0618	0·005	2·73		0·01
Dimethylmesidine	—	—	—		—	0·2310	0·02	5·13	5·15	0·01
						0·1226	0·02	5·17		0·01
Diethylaniline	—	—	—		—	0·0749	0·01	5·85		0·02
p-Nitrosodiethylaniline	—	—	—		—	0·0356	0·002	3·56		0·04
Di-*n*-butylaniline *	—	—	—		—	—	—	4·84		—
Phenyldimethylphosphine	—	—	—		—	0·0472	0·01	4·33	4·32	0·08
						0·0449	0·01	4·31		0·10
p-Tolyldimethylphosphine	—	—	—		—	0·1360	0·02	4·66		0·15
p-Xylyldimethylphosphine	—	—	—		—	0·1104	0·01	4·38	4·40	0·15
						0·1701	0·02	4·43		0·15
Mesityldimethylphosphine *	—	—	—		—	0·0920	0·01	6·49	6·51	0·05
						0·1695	0·02	6·53		0·01
Phenyldiethylphosphine	—	—	—		—	0·0890	0·01	4·29	4·37	0·10
						0·0520	0·01	4·49		0·11
						0·0421	0·005	4·34		0·08
Phenyldi-*n*-butylphosphine †	—	—	—		—	—	—	3·80		—
Mesityldimethylarsine	—	—	—		—	0·1074	0·01	2·11		0·10

Phenyldimethyl-, phenyldiethyl-arsine, *p*-dimethylaminobenzaldehyde, *m*-, *p*-nitrodimethylaniline and *p*-nitrodiethylaniline were too weak to be measured accurately by the present method.

* Single determination of the p_H of 0·1049 g. of the base and 35 c.c. of 0·02*N*-hydrochloric acid diluted to 100 c.c. with solvent.

† Single determination of the p_H of 0·1538 g. of the base and 30 c.c. of 0·02*N*-hydrochloric acid diluted to 100 c.c. with solvent.

The opportunity has also been taken of measuring the dissociation constants of a number of substituted dimethylanilines, in view of the paucity of results hitherto obtained.

The table gives a full list of the results now obtained. The value of p_K given is the mean of four or five determinations with successive amounts of hydrochloric acid in a titration.

In view of the almost non-basic character of phosphine, it was remarkable to find that the basic strength of a tertiary phosphine was comparable with that of an amine. In the simplest case, phenyldimethylphosphine is actually a slightly stronger base than dimethylaniline. In other cases, the size of the central atom seems to play a part, for example, in damping the effect of a nuclear substituent, but even then the strengths of amine and phosphine are not very different. Tertiary arsines, on the other hand, are extremely weak bases. Phenyldimethyl- and phenyldiethyl-arsines were too weak to be measured by the present method. Mesityldimethylarsine, the dissociation constant of which was measured, is notably weaker than dimethylmesidine. Thus the substitution of organic groups for hydrogen in phosphine enhances the basic strength to a greater extent than it does in ammonia, for ammonia is already relatively to phosphine a strong base. Explanation is as yet obscure, since it would be expected on account of the greater size of the phosphorus atom than the nitrogen atom that the availability of the lone electron pair of the central element due to the electronic effects of the attached organic groups would be slightly smaller in the phosphine than in the amine. Our results show that increase in the size of the central atom causes a diminution of the polar effects of the attached groups at the point of reaction, but that this circumstance must be of relative unimportance compared with some other factor operating when organic groups are substituted into ammonia or phosphine.

The order of reactivity of the tertiary bases with alkyl halides, phosphine > arsine > amine, is not the order of their basic strengths, which is amine and phosphine almost equal and much stronger than the arsine. Possibly the mechanisms of formation of a basic hydroxide and of an alkylhalide are different, but also some factors may be more prominent in the one than in the other; for instance, certain steric effects may be absent in the basic hydroxide formation but present in the formation of the quaternary salt.

Organic Substituents attached to the Central Atom.—No satisfactory explanation has been given of the fact that diethylaniline is a much stronger base than dimethylaniline: on electronic grounds it should be only slightly stronger. Phenyldiethylphosphine is only slightly stronger than phenyldimethylphosphine. It might appear that the anomaly has disappeared, but it should be remembered that the electronic effects of the ethyl groups should be less in the phosphine than in the amine owing to the increased size of the central atom. Support is given to this conclusion by comparing the strengths of phenyldi-*n*-butyl-amine and -phosphine with the lower phenyldialkyl-amines and -phosphines. The reactivity of dimethylaniline towards alkyl halides is much greater than that of diethylaniline (see, for example, Davies and Lewis, *loc. cit.*), so it must be concluded that steric effects in this case are more important than polar effects.

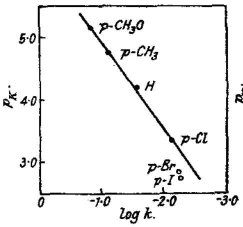
o-*Substituents in the Phenyldialkyl-bases.*—Examination of the dissociation constants of the bases with *o*-nuclear substituents shows that steric effects are probably absent. An *o*-methyl group in dimethylaniline increases the basic strength of the unsubstituted base, even more than does a *p*-methyl substituent. Only a slight increase arises from a *m*-methyl substituent. Similar effects appear to be present in the phosphines, but to a smaller extent. Thus, *p*-xylyldimethylphosphine is only a slightly stronger base than phenyldimethylphosphine, that is, the *m*-methyl group, as in the amines, has only a small effect, and also the *o*-methyl group has only a slight activating effect.

These results are sharply contrasted with the reactivities of bases towards alkyl halides (Thomas, J., **1913**, **103**, 594; Davies and Lewis, *loc. cit.*). A *p*-methyl group increases the reactivity of the unsubstituted base, but an *o*-methyl group causes a notable decrease in its reactivity. Whereas polar factors decide the strength of the compound as a base, the steric factor is uppermost in determining its reactivity towards alkyl halides. Steric factors are practically absent in the *m*- and *p*-substituted compounds both in basic hydroxide and in quaternary salt formation. The difference observed between the effect of the *o*-methyl groups on the formation of the basic hydroxide and the quaternary salt is due to the difference in size of the hydrogen atom and the alkyl group which are co-ordinated by the tertiary compound.

The non-reactivity of dimethylmesidine towards methyl iodide (Hofmann, *Ber.*, 1872, 5, 718) is a classic example of steric hindrance. Hofmann's method of attempting to obtain the salt was incorrect, *viz.*, heating the generators in a sealed tube at 150°, since such treatment would tend to decompose any salt formed, the formation of quaternary salts being in general a reversible reaction (Davies and Cox, this vol., p. 618). Nevertheless, the lenity of the formation of the methiodide is beyond question. At room temperature a mixture of the amine, excess of methyl iodide, and anhydrous ether only deposited a trace of a crystalline substance after 2 months. On the other hand we now see that dimethylmesidine is a base stronger even than dimethyl-*o*-toluidine. Only a small quantity of mesityldimethylphosphine was available and without further confirmation we do not attach any great significance to the very high result obtained. It has already been mentioned that mesityldimethylarsine is the strongest aryldialkylarsine we have investigated.

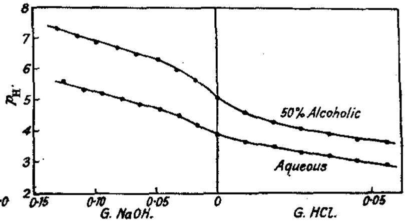
An important difference will be noted in comparing the strengths of the primary and the secondary aromatic bases with the tertiary phenyldialkyl-bases. The order of strengths of the primary bases is *o*-toluidine < aniline < *m*-toluidine < *p*-toluidine, and that of the secondary bases is similar, methyl-*o*-toluidine < methyl-*m*-toluidine < methyl-*p*-toluidine.

Fig. 1.



Dissociation constants and velocity coefficients of reaction with methyl iodide of p-*substituted dimethylanilines.*

Fig. 2.



p_H *values of aqueous and* 50 *per cent. alcoholic solutions of potassium hydrogen phthalate + hydrochloric acid or sodium hydroxide. The acid was added as a* 0·05N-*solution in each case, and the alkali as a* 0·079N-*solution in the aqueous medium and as a* 0·082N-*solution in the alcoholic medium, to* 75 *c.c. of* 0·05M-*potassium hydrogen phthalate.*

With the dimethyltoluidines, however, we have *o* > *p* > *m* > dimethylaniline. Following Bennett and Mosses (J., 1930, 2364) the postulation of a direct effect of the *o*-methyl group of sign opposite to its usual polar effect would explain the weakness of *o*-toluidine and methyl-*o*-toluidine. However, this suggestion does not explain the great strength of dimethyl-*o*-toluidine. The results suggest that in the primary and the secondary bases the hydrogen attached to the nitrogen atom is involved in some way with the *o*-substituent, but a precise formulation is difficult. The sequences observed are not confined to a methyl substituent. For instance, Hall and Sprinkle (*J. Amer. Chem. Soc.*, 1932, 54, 3469) gave the following order of strengths: *o*-anisidine < aniline < *p*-anisidine, and the present work gives dimethyl-*o*-anisidine > dimethyl-*p*-anisidine > dimethylaniline.

p-*Substituents in the Phenyldialkyl-bases.*—The following is the order of strengths of the *p*-substituted phenyldimethylamines: EtO>MeO>Me>H>F>NO>Cl>Br>I>NO_2. In the *p*-alkoxy-compounds it must be the electromeric effect which operates in determining the basic strength. The position of the nitroso-group indicates that it is the displacement —N=O which operates in determining the effect of this group on the basic strength of dimethylaniline (cf. Robinson, *Chem. and Ind.*, 1925, 44, 456). In the phosphine series the effects of *p*-substituents are in the same direction, but are generally weaker, since the electronic effect of the substituent is not transmitted so well through the heavier atom. A similar conclusion was reached by Davies and Lewis (*loc. cit.*) from a comparison of the rates of addition of alkyl halides to *p*-substituted phenyldialkyl-amines and -phosphines.

Since steric effects due to the *p*-substituent should be negligible, a simple relation between the reactivity, for instance, towards methyl iodide, of a series of *p*-substituted dimethylanilines and their dissociation constants is to be expected (see Hammett, *Chem. Reviews*, 1935, **17**, 125). A straight line (Fig. 1) is obtained when the values obtained by Davies and Lewis for log k_{35° (bimolecular velocity coefficient) for the reaction between methyl iodide and *p*-substituted dimethylanilines in 90% acetone are plotted against the p_K (50% alcohol) of the bases. The *p*-bromo- and *p*-iodo-bases show slight deviations, but in these cases the velocity coefficients are probably only approximate owing to the experimental difficulties mentioned by Davies and Lewis.

Experimental.

Materials and Procedure.—Dimethyl- and diethyl-aniline and the *N*-dimethyltoluidines were purified by treatment with acetic anhydride and fractionation. Dimethyl-*p*-anisidine and dimethyl-*p*-phenetidine were prepared by the method of Davies (*Bull. Soc. chim.*, 1935, **2**, 295), and the *p*-halogenodimethylanilines by that of Davies and Cox (*loc. cit.*). *p*-Nitroso-dimethylaniline and -diethylaniline were recrystallised from acetone.

Di-*n*-butylaniline was prepared as follows: a mixture of aniline (31 g.), *n*-butyl iodide (123 g.), sodium hydroxide (27 g.), and *n*-butyl alcohol (120 g.) was heated for 12 hours at 160—180° in an autoclave. The product was steam-distilled, the oil treated with acetic anhydride, and the mixture fractionated under reduced pressure. The amine fraction was redistilled, yielding 40 g., b. p. 270° (corr.) (Reilly and Hickinbottom, J., 1917, **111**, 1016; 1918, **113**, 99, gave b. p. 260—263°).

Nitromesitylene ("Organic Syntheses," Vol. XIV) was reduced by means of tin and boiling concentrated hydrochloric acid. The product was diluted with water, made alkaline, and steam-distilled. The aminomesitylene was methylated by Sudborough and Roberts's method (J., 1904, **85**, 236), and the dimethylmesidine purified by treatment with acetic anhydride, steam-distillation, and fractionation.

Tertiary phosphines and arsines were purified by two distillations under reduced pressure, great care being taken to exclude air throughout their preparation and subsequent manipulations.

30% or 50% Alcohol was made by diluting 30 or 50 vols. of absolute ethyl alcohol to 100 vols. with water.

Solutions were made by weighing the bases into graduated flasks and diluting them with solvent, vigorous shaking and sometimes the use of slightly warmed solvent being necessary; generally solutions more concentrated than *M*/100 could not be obtained, and sometimes *M*/500 was the strongest solution obtainable. Phosphines and arsines were weighed in small capillary-necked tubes, which were filled and sealed immediately after the final distillation of the base. The tube was then broken under the solvent in a stoppered graduated flask. For the titration a known volume of the solution of the base was removed to a beaker, which was kept in an oil-bath at 20°. The glass electrode and the side-arm of the calomel half cell were supported in the beaker, which was open for the amines, but in the case of the phosphines and arsines was fitted with a stopper, and a current of nitrogen was passed over the surface of the solution. The *E.M.F.* of the cell was then determined, after the addition of each portion of standard hydrochloric acid, by means of a Cambridge Valve Potentiometer.

Standardisation of the glass electrode in 30% alcohol was carried out as suggested by Bennett, Brooks, and Glasstone (*loc. cit.*) with a series of buffer solutions (Britton and Robinson's mixture; J., 1931, 1456) whose p_H's had been determined by means of a hydrogen electrode. The latter was a wire form described by Lockwood (*J. Soc. Chem. Ind.*, 1935, **54**, 295T). For the standardisation of the glass electrode in 50% alcohol, a number of solutions were made by adding 0·0822*N*-sodium hydroxide or 0·05*N*-hydrochloric acid to 0·05*M*-potassium hydrogen phthalate (each in 50% alcohol). Fig. 2 gives the p_H values of the solutions, obtained with a hydrogen electrode, compared with the results for similar aqueous solutions. It will be seen that the behaviour of the salt on treatment with acid or alkali is similar with either water or 50% alcohol as medium.

The calibration of the glass electrode was checked frequently, but a good electrode remained constant for considerable periods. It was observed from many series of calibrations that the straight line obtained by plotting the p_H's (obtained with a hydrogen electrode) of a series of buffer solutions against the *E.M.F.*'s of cells containing a given glass electrode and these solutions was hardly affected by change of medium from water to 50% alcohol. The following figures can be used for an example:

Buffer solutions : 0·05*M*-potassium hydrogen phthalate + sodium hydroxide or hydrochloric acid.

Aqueous medium.									
p_H of solution (hydrogen electrode)	5·58	5·19	4·86	4·48	3·86	3·65	3·34	3·05	2·91
E.M.F. of cell containing glass electrode	0·099	0·126	0·146	0·169	0·203	0·211	0·234	0·248	0·255
50% *Alcoholic medium.*									
p_H of solution (hydrogen electrode)	7·30	6·85	6·46	5·99	5·04	4·58	4·08	3·77	3·65
E.M.F. of cell containing glass electrode	−0·002	0·028	0·051	0·075	0·131	0·157	0·186	0·204	0·211

The linear calibration holds fairly exactly with the present glass electrodes up to $p_H = 11$, both in aqueous solution and in 30% alcohol.

The following tables give some complete examples.

p-*Fluorodimethylaniline.*

0·0695 G. of base diluted to 100 c.c. 0·01*N*-Hydrochloric acid.

Solvent :	30% Alcohol.					50% Alcohol.				
Acid, c.c.	10	20	30	40		10	20	30	40	
p_H	5·08	4·69	4·325	3·865		4·65	4·24	3·89	3·51	
p_K	4·48	4·51	4·50	4·45	Mean 4·49	4·05	4·06	4·01	3·93	Mean 4·01

	p-*Xylyldimethylphosphine.* 0·1104 G. of base diluted to 100 c.c. with 50% alcohol.				*Mesityldimethylarsine.* 0·1075 G. of base diluted to 100 c.c. with 50% alcohol.			
0·01*N*-HCl, c.c.	10	20	30		10	20	30	
p_H	5·28	4·80	4·275		3·26	2·93	2·765	
p_K	4·53	4·43	4·19	Mean 4·38	2·21	2·08	2·05	Mean 2·11

It will be observed that in a titration of phosphine or arsine with acid the values of p_K are not quite as constant as in that of an amine. This is probably due to the difficulty in handling these bases. Furthermore, the glass electrode does not attain equilibrium as quickly in mixtures of phosphines or arsines and mineral acid as it does in the amine solutions.

Titration of Very Weak Bases.—The p_H's of mixtures of solutions of very weak bases and hydrochloric acid are hardly distinguishable from those of plain hydrochloric acid solutions of the same concentrations. If moderately concentrated solutions can be made, fairly accurate results may be obtained in some cases. The following table shows that the basic constant of *o*-aminobenzoic acid can be measured, but it should be pointed out that in experiment 3 the difference between the *E.M.F.*'s of a cell containing the weak base–acid mixture and one containing the acid alone is only 5 mv. No determination of the basic constant of *p*-dimethylaminobenzaldehyde was possible by the present method. Some very low values of p_K appearing in the literature and obtained by the electrometric titration method must on this account be accepted with reserve, especially where the concentrations employed have not been specifically stated.

Basic Constant of* o-*Aminobenzoic Acid in* 50% *Alcohol.

	p_H.	p_K.
(1) Equal vols. of 0·08*N*-*o*-aminobenzoic acid and 0·04*N*-HCl	2·00	1·62
0·02*N*-HCl	1·73	—
(2) Equal vols. of 0·04*N*-*o*-aminobenzoic acid and 0·02*N*-HCl	2·21	1·58
0·01*N*-HCl	2·08	—
(3) Equal vols. of 0·02*N*-*o*-aminobenzoic acid and 0·01*N*-HCl	2·40	1·55
0·005*N*-HCl	2·32	—

p-***Dimethylaminobenzaldehyde.***

Addition of 0·04*N*-hydrochloric acid to 50 c.c. of 0·02*N*-*p*-dimethylaminobenzaldehyde. Solvent, 50% alcohol.

Acid, c.c.	5	10	15	20
p_H	2·45	2·20	2·06	1·99

Addition of 0·04*N*-hydrochloric acid to 50 c.c. of 50% alcohol.

Acid, c.c.	5	10	15	20
p_H	2·45	2·18	2·04	1·99

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NOTE.

Reactive Methylene Groups and Nitroso-compounds. By ERNST BERGMANN.

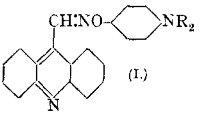
SCHOENBERG and MICHAELIS (this vol., p. 627) report the formation of a nitrone from 3 : 3-diphenylhydrindone and nitrosobenzene or *p*-nitrosodimethylaniline, and suggest the following most reasonable mechanism :

$$R{\cdot}CH_2{\cdot}CO{\cdot}R' \longrightarrow \underset{N(OH){\cdot}Ar}{R{\cdot}CH{\cdot}CO{\cdot}R'} \xrightarrow{-H_2} \underset{O{=}NAr}{R{\cdot}C{\cdot}CO{\cdot}R'}$$

The analogous reaction was observed by Leiser and the author some years ago in the case of fluorene and 2 : 7-dibromofluorene, which react with *p*-nitrosodimethylaniline to give *p*-dimethylaminophenyldiphenylenemethylenenitrone and its 2′ : 7′-dibromo-derivative, respectively, instead of the anil, as supposed by Novelli (*Centr.*, 1928, I, 1410). *Fluorene (3 g.) and p-nitroso*dimethylaniline (3 g.) in alcohol (300 c.c.) were boiled with sodium ethoxide (sodium, 0·46 g.; alcohol, 40 c.c.) for 4 hours; the mass was diluted with water, extracted with ether, and the resinous ethereal residue triturated with acetone at 0°. The crystalline product, recrystallised from propyl alcohol, formed quadrilateral prisms, m. p. 224° (decomp.), identical with the nitrone, prepared from 9-chlorofluorene and nitrosodimethylaniline (Bergmann and Hervey, *Ber.*, 1929, **62**, 893) (Found : N, 8·8. Calc. for $C_{21}H_{18}ON_2$: N, 8·9%).

In the same way, 2 : 7-dibromofluorene (Sieglitz, *Ber.*, 1920, **53**, 1236) gave p-*dimethylaminophenyl-2′ : 7′-dibromodiphenylenemethylenenitrone*, which crystallised spontaneously from the reaction mixture and was collected and washed with methanol; brown-violet needles, from *anisole, m. p. 224° (decomp.) (Found : C, 53·8; H, 3·5; N, 5·9; Br, 33·6.* $C_{21}H_{16}ON_2Br_2$ requires C, 53·4; H, 3·4; N, 5·9; Br, 33·9%). In both cases, the mother-liquors contain azoxydimethylaniline, which is the main product—apparently formed by direct interaction between the nitroso-compound and the ethoxide (Ehrlich and Sachs, *Ber.*, 1899, **32**, 2341; Hantzsch and Lehmann, *Ber.*, 1902, **35**, 905)—when the reaction is carried out in benzene solution.

The mechanism suggested by Schoenberg and Michaelis accounts for the formation of deeply coloured products from 9-methylacridine and *p*-nitrosodialkylanilines (Kaufmann and Vallette, *Ber.*, 1912, **45**, 1736; Poraí-Koschitz, Auschkap, and Amsler, *Centr.*, 1911, II, 289); these products probably contain two hydrogen atoms less than assumed by the previous authors and should be formulated as in (I). In these cases the formation of the expected anils among the products was also reported. We were unable to isolate the *anil* from the reaction between fluorene and *p*-nitrosodimethylaniline, but we prepared it by boiling fluorenone (2·7 g.) and *p*-dimethylaminoaniline (4·2 g.) with a few drops of dilute hydrochloric acid (Reddelien, *Ber.*, 1913, **46**, 2718). The red resin so obtained was triturated with methanol, and crystallised from alcohol, forming red prisms, m. p. 100° (*Found :* C, 84·4; H, 6·2. $C_{21}H_{18}N_2$ requires C, 84·5; H, 6·0%).



(I.)

Finally, it is suggested that nitrone formation from safrole and nitrosobenzene (Alessandri *et al.*, *Centr.*, 1910, II, 302; 1915, I, 1210) is also based on the presence of an activated methylene group, although the reaction proceeds with migration of the double bond. Here again, part of the nitrosobenzene is reduced by the primary product to give azoxybenzene, for the formation of which no satisfactory explanation has hitherto been proposed. This mechanism accounts for the fact that *iso*safrole is resistant to the action of nitrosobenzene; although it contains preformed the unsaturated system as present in the end product of the above reaction, yet the necessary reactive methylene group is missing.—THE DANIEL SIEFF RESEARCH INSTITUTE, REHOVOTH (PALESTINE). [*Received, June 24th,* 1937.]

341. *The Constitution and Reactions of Thiocarbonyl Tetrachloride. Part IV. Reaction with Secondary and Tertiary Amines.*

By Christopher S. Argyle and G. Malcolm Dyson.

Secondary arylalkylamines have been shown to react with thiocarbonyl tetrachloride to give very unstable compounds of the type $NR_1R_2{\cdot}S{\cdot}CCl_3$, but with diarylamines the reaction is more complex and triphenylmethane dyes are formed together with a new, deep red substance, which is similar to the triphenylmethane dyes in structure but retains at least one diarylamino-group attached to the methane carbon atom through the nitrogen atom.

Tertiary amines and thiocarbonyl tetrachloride yield dyes of the crystal-violet type when heated alone or in the presence of condensing agents such as zinc or aluminium chloride. The mechanism of this reaction has been elucidated by the isolation of substances of the type $NR_2{\cdot}C_6H_4{\cdot}S{\cdot}CCl_3$, the $\cdot S{\cdot}CCl_3$ group of which is capable of furnishing the methane carbon of the triphenylmethane structure.

Investigation of the reaction between thiocarbonyl tetrachloride and primary arylamines (J., 1935, 679) has been extended to secondary and tertiary amines. Dialkyl- and arylalkylamines give S-*dialkyl-* and S-*arylalkyl-aminotrichloromethylthiols*, $NR_1R_2{\cdot}S{\cdot}CCl_3$ (I), colourless or pale yellow oils. The former distil readily in a vacuum, but most of the latter compounds are unstable at the ordinary temperature and in no case distil unchanged. Thermal decomposition of S-arylalkylaminotrichloromethylthiols gives thiocarbonyl tetrachloride, the hydrochloride of the original amine, the arylthiocarbimide, and the alkyl chloride. For instance, from S-methylanilinotrichloromethylthiol, thiocarbonyl tetrachloride, methylaniline hydrochloride, phenylthiocarbimide, and methyl chloride are obtained by decomposition at 140°:

$$Ph{\cdot}NMe{\cdot}S{\cdot}CCl_3 \longrightarrow CH_3Cl + Ph{\cdot}N{<}^{S}_{CCl_2}\,;\quad 2Ph{\cdot}N{<}^{S}_{CCl_2} \longrightarrow Ph{\cdot}NCS + Ph{\cdot}NH_2 + CSCl_4$$

With dry hydrogen chloride in ligroin, these thiols (I) quantitatively regenerate the hydrochloride of the original amine and thiocarbonyl tetrachloride; reduction with zinc dust and glacial acetic acid gives methylthiol; excess of arylamine in ligroin gives a triarylguanidine hydrochloride. The thiols are hydrolysed slowly by boiling water, more readily by boiling 20% aqueous alkali, to give carbylamines and thiocarbimides, methyl-*p*-toluidinotrichloromethylthiol yielding under these conditions both *p*-tolylcarbylamine and *p*-tolylthiocarbimide.

With diarylamines, the reaction takes an entirely different course. Diphenylamine and thiocarbonyl tetrachloride give NN′N″-*triphenylpararosaniline hydrochloride* (II) and a *compound*, (III) or (IV). An identical mixture of coloured products is obtained also

$$\text{(III.)}\quad C(NPh_2)_2{:}C_6H_4{:}NHPhCl \qquad C(NPh_2)(C_6H_4{\cdot}NHPh){:}C_6H_4{:}NHPhCl\quad \text{(IV.)}$$

from diphenylamine and thiocarbonyl chloride; in dilute ethereal solution they give tetraphenylthiocarbamide (Bergreen, *Ber.*, 1888, **21**, 340), followed by a considerable quantity of dark red products, better obtained by heating diphenylamine and thiocarbonyl chloride or tetrachloride in absence of solvent.

Chloropicrin, trichloromethanesulphonyl chloride, and S-*p*-tolyltrichloromethylthiol react similarly with diphenylamine at 150°:

$$CCl_3{\cdot}NO_2 + 3NHPh_2 = C_{37}H_{30}N_3Cl + HNO_2 + 2HCl$$
$$CCl_3{\cdot}SO_2Cl + 3NHPh_2 = C_{37}H_{30}N_3Cl + SO_2 + 3HCl$$
$$CCl_3{\cdot}S{\cdot}C_6H_4Me + 3NHPh_2 = C_{37}H_{30}N_3Cl + C_6H_4Me{\cdot}SH + 2HCl$$

NN′N″-Triphenylpararosaniline hydrochloride (II) is identical in solubilities with that obtained from carbonyl chloride and diphenylamine; it dyes wool mordanted with alumina a deep blue, and is completely reduced by nascent hydrogen to a colourless leuco-base, the colour reappearing on addition of a mild oxidising agent, *e.g.*, calcium hypochlorite. Concentrated sulphuric acid dissolves it with a brownish-yellow colour, a blue precipitate

being produced on dilution; further action of the acid gives first an insoluble monosulphonic acid and then a trisulphonic acid, easily soluble in water. Solutions of the compound in alcohol give a red colour with alkali, gradually fading; immediate extraction with ether gives a red basic compound (picrate, bronze needles, blue solution in benzene).

The red compound, oxidised with alkaline potassium permanganate, gives phenylcarbylamine, indicating the presence of a Ph·N·C· group; from the oxidation with acid *potassium permanganate*, *diphenylamine* was isolated, indicating a NPh_2· link. With sodium hydroxide, it forms a red ether-soluble base, the colour gradually fading on standing; reduction with zinc and hydrochloric acid gives a colourless compound. When warmed with concentrated sulphuric acid, it gives an insoluble monosulphonic acid, and with fuming nitric acid in glacial acetic acid it affords *pp'*-dinitro-*N*-nitrosodiphenylamine, from which *pp'*-dinitrodiphenylamine was prepared. A vigorous reaction takes place with acetyl chloride in acetic anhydride, but the acetyl compound could not be isolated in the crystalline state. Dry distillation of the red compound gives diphenylamine (cf. *NN'N''-triphenylpararosaniline hydrochloride*).

These properties indicate that the compound is of the triphenylmethane-dye type, containing one or two diphenylamino-groups intact, the bulk of evidence confirming the former (see IV).

The initial formation of tetraphenylthiocarbamide and the final formation of (II), in the reaction between thiocarbonyl chloride and diphenylamine, probably occurs by a series of para-migrations, comparable with those of the semidine and the benzidine transformation:

$$C(NPh_2)_2{:}S \longrightarrow NPh_2{\cdot}CS{\cdot}C_6H_4{\cdot}NHPh \longrightarrow NHPh{\cdot}C_6H_4{\cdot}CS{\cdot}C_6H_4{\cdot}NHPh$$

At the same time, diphenylthiocarbamyl chloride is formed, and reacts with the migration products. This supposition is based on the behaviour of other secondary amines with thiocarbonyl chloride: dimethyl- and diethyl-amine both react with it on warming, but dipropylamine must be subjected to prolonged boiling with it in toluene before reaction proceeds to the tetrapropylthiocarbamide stage (Delépine, *Bull. Soc. chim.*, 1910, **7**, 989). As the molecular weight of the groups increases, there is an increasing tendency for the reaction to stop at the dialkyl- or diaryl-thiocarbamyl chloride: in the case of arylalkylamines, *e.g.*, ethylaniline, this is the main product of the reaction. Hence, in this case, diphenylthiocarbamyl chloride is probably formed and immediately reacts with diphenylamine, giving some tetraphenylthiocarbamide, and also with both migration products of the latter, giving, in the first case, the red compound (III or IV) and, in the case of the doubly migrated compound, the hydrochloride (II). In accordance with this view, di-*p*-tolylamine gives no coloured products.

The balance of the evidence points to formula (IV) as the structure of the red component.

Tertiary Amines.—Rathke (*Ber.*, 1886, **19**, 397) noted that a violet dye was formed when thiocarbonyl tetrachloride and dimethylaniline react. He suggested that it was produced by partial decomposition of the tetrachloride into sulphur and carbon tetrachloride, which then reacted separately, thus:

$$S + 2C_6H_5{\cdot}NMe_2 = S(C_6H_4{\cdot}NMe_2)_2 + 2H \quad . \quad . \quad . \quad . \quad . \quad (i)$$

$$CCl_4 + 3C_6H_5{\cdot}NMe_2 = C(C_6H_4{\cdot}NMe_2)_3Cl + 3HCl \quad . \quad . \quad . \quad . \quad . \quad (ii)$$

Further decomposition of thiocarbonyl tetrachloride he assumed to give chlorine and thiocarbonyl chloride, the former rendering ineffective much of the hydrogen of the reaction (i), and the latter converting a portion of the dimethylaniline into 4 : 4'-bis(dimethylamino)-diphenyl thioketone (Michler's thioketone). Since he did not isolate the thioketone, and suggested the probable formation of another sulphur compound to account for the low yield of dye, it was considered desirable to reinvestigate the reaction.

Thiocarbonyl tetrachloride and dimethylaniline gave S-p-*dimethylaminophenyltrichloromethylthiol*, $NMe_2{\cdot}C_6H_4{\cdot}S{\cdot}CCl_3$ (V), and tris-*p*-dimethylaminophenylmethane, in addition to crystal-violet. The thiol is analogous to the various *p*-substituted aryltrichloromethylthiols described by Zincke, Jörgensen, and Frohneberg (*Ber.*, 1909, **42**, 2721; 1910, **43**, 837).

The thiol (V) is hydrolysed by water to carbon dioxide, hydrogen chloride (traces of

hydrogen sulphide), and *p*-dimethylaminophenylthiol; reduction gives some dimethylaniline and methylthiol; concentrated nitric acid in glacial acetic acid gives a *dinitro*-derivative, and dry hydrogen chloride in ligroin quantitatively precipitates the hydrochloride. The compound reacts readily with primary arylamines giving S-(p-*dimethylaminophenyl*)-*NN'-diarylisothiocarbamides* (VI), the constitution of which has been established by hydrolysis in alcoholic ammonia solution at 120° to *p*-dimethylaminophenylthiol and diarylguanidines (VII; R' = H):

$$\text{(VI.)}\quad NMe_2{\cdot}C_6H_4{\cdot}S{\cdot}C(\colon NR){\cdot}NHR + NH_3 = NMe_2{\cdot}C_6H_4{\cdot}SH + NR'\colon C(NHR)_2 \quad \text{(VII.)}$$

With alcoholic aniline at 170°, the compounds (VI) give *p*-dimethylaminophenylthiol and triarylguanidines (VII; R' = Ph). With chloroform and alcoholic potash they give carbylamines; reduction with tin and hydrochloric acid regenerates the primary amine from which they were prepared; and they are unaffected by aqueous alkalis weaker than 80% potassium hydroxide, which gives some *p*-dimethylaminophenylthiol.

Compounds of the type (VI) have been prepared alternatively from carbodiaryldi-imide monohydrochloride and potassium *p*-dimethylaminophenylthiol:

$$NMe_2{\cdot}C_6H_4{\cdot}SK + CCl(\colon NR){\cdot}NHR = NMe_2{\cdot}C_6H_4{\cdot}S{\cdot}C(\colon NR){\cdot}NHR$$

[cf. formation of tetraphenyl*iso*thiocarbamide: $Ph{\cdot}SNa + CCl(\colon NPh){\cdot}NPh_2 = Ph{\cdot}S{\cdot}C(\colon NPh){\cdot}NPh_2$, and of diphenylethyl*iso*carbamide: $EtONa + CCl(\colon NPh){\cdot}NHPh = C(OEt)(\colon NPh){\cdot}NHPh$ (*Ber.*, 1903, **36**, 965; 1895, **28**, Ref. 778)].

S-Arylaminotrichloromethylthiols react with diarylamines, and, in presence of condensing agents, *e.g.*, aluminium chloride or zinc chloride, with aromatic tertiary amines, to give dyes identical with those obtained from thiocarbonyl tetrachloride and the corresponding amine, the same dyes being produced from diphenylmethylamine directly with thiocarbonyl tetrachloride and indirectly with the thiol (V):

$$NMe_2{\cdot}C_6H_4{\cdot}S{\cdot}CCl_3 + 3NPh_2Me \longrightarrow [NMe_2{\cdot}C_6H_4{\cdot}S{\cdot}C(C_6H_4{\cdot}NMePh)_3] \longrightarrow NMe_2{\cdot}C_6H_4{\cdot}SH + C(\colon C_6H_4\colon NMePhCl)(C_6H_4{\cdot}NMePh)_2$$

Diphenylamine reacts similarly, and dimethylaniline condenses with the thiol in presence of aluminium chloride to give crystal-violet. The rate of reaction of dialkylanilines with thiocarbonyl tetrachloride diminishes with increase in the size of the alkyl groups.

Triphenylamine reacts with thiocarbonyl chloride or tetrachloride at 180° to give hexaphenylrosaniline hydrochloride.

p-Bromo-dimethyl- and -diethyl-aniline, dimethyl-*p*-toluidine, and tetramethyldiaminodiphenylmethane react rapidly with thiocarbonyl tetrachloride on heating, with partial demethylation, thiocarbonyl chloride distilling. Tribenzylamine, similarly, gives benzyl chloride and thiocarbonyl chloride.

EXPERIMENTAL.

S-*Dimethylaminotrichloromethylthiol*, $NMe_2{\cdot}S{\cdot}CCl_3$.—Dimethylamine (33% aqueous solution) was added slowly to a well-stirred mixture of thiocarbonyl tetrachloride (20 g.) in ether (150 ml.) and sodium hydroxide (8 g.) in water (250 ml.) kept below 30°, until a slight excess of amine was present. After 15 minutes, the ethereal layer was removed, the residue extracted with ether (25 ml.), and the combined extracts washed with water, dried over potassium carbonate, and freed from ether in a vacuum at 15°. The residual S-*dimethylaminotrichloromethylthiol* distilled as a colourless oil, b. p. 74°/15 mm., with a characteristic odour (Found: S, 16·9. $C_3H_6NCl_3S$ requires S, 16·5%).

The following analogues were prepared: *Diethyl* compound, colourless oil, b. p. 96°/15 mm. (Found: S, 14·6. $C_5H_{10}NCl_3S$ requires S, 14·4%); di*iso*butyl compound, pale yellow oil, b. p. 127°/15 mm. (decomp.).

Arylalkylaminotrichloromethylthiols were prepared as pale yellow, unstable oils by the above method, sodium hydroxide being replaced by sodium carbonate: *Methylanilino*-compound, with characteristic odour (Found: S, 12·8. $C_8H_8NCl_3S$ requires S, 12·5%); *methyl*-p-*toluidino*-compound (Found: S, 12·2. $C_9H_{10}NCl_3S$ requires S, 11·8%). The corresponding ethylanilino-, ethyl-*o*-toluidino-, and ethyl-α-naphthylamino-compounds (pale yellow oils) were prepared but were excessively unstable.

S-Dibenzylaminotrichloromethylthiol (colourless oil) decomposed on attempted distillation

in a vacuum, giving a distillate containing a large proportion of benzyl chloride, b. p. 179—180° (*p*-nitro-derivative, m. p. 71°). The benzylanilino-compound was not isolated owing to instability.

Reduction of S-dimethylaminotrichloromethylthiol. The thiol (5 g.) was dropped slowly on zinc dust (50 g.) and glacial acetic acid (50 ml.), and the mixture heated until reaction commenced. The gases evolved were passed through two tubes (20 × 9 cm.), the first containing anhydrous calcium chloride, and the second finely-crystallised lead acetate (20 g.); with the latter was connected a small wash-bottle containing 1 ml. of a fresh solution of isatin (10 mg.) in concentrated sulphuric acid (100 ml.). When air was passed through the system, any hydrogen sulphide was held by the lead acetate, and methylthiol produced a grass-green colour with the isatin reagent.

Reaction with aniline. *S*-Dimethylaminotrichloromethylthiol (20 g.) in ligroin (150 ml.) was boiled under reflux for 10 hours with aniline (45 g.). The ligroin was decanted, the residue distilled in steam, and the hot solution filtered from sulphur. Triphenylguanidine hydrochloride, which separated from the cooled filtrate, was filtered off and converted by sodium hydroxide solution into the base; colourless needles (17 g.) from alcohol, m. p. 143°; picrate, yellow needles, m. p. 179°.

The yields of triphenylguanidine obtained from other trichloromethylthiols are shown in the table below:

Trichloromethylthiol.	% Yield of triphenylguanidine.	Trichloromethylthiol.	% Yield of triphenylguanidine.
S-Diethylamino-	60	*S*-Ethylanilino-	32
S-Diisobutylamino-	46	*S*-Methyl-*p*-toluidino-	37
S-Methylanilino-	35	*S*-Piperidyl-	28

NN′N″-*Triphenylpararosaniline Hydrochloride* (II) *and an Isomeric Red Compound* (?IV).—(*a*) Diphenylamine (20 g.) and thiocarbonyl chloride or tetrachloride (10 g.) were warmed until violent effervescence started; reaction then proceeded without the aid of external heat. The cooled melt was warmed first with acetone (20 ml.), the solution being rejected, then with ether (150 ml.) to remove tetraphenylthiocarbamide and the excess of diphenylamine, and finally extracted with acetone (200 ml.), the cooled (0°) extract being poured into pure dry ether (1 l.). The whole was kept for an hour, and the precipitated *compound* (IV) was collected, washed with ether, and dried in a vacuum over concentrated sulphuric acid; it formed deep red, micro-crystals from amyl alcohol, m. p. 280° (decomp.) (Found: H, 5·8; Cl, 6·3. $C_{37}H_{30}N_3Cl$ requires H, 5·4; Cl, 6·5%).

(*b*) Three portions of diphenylamine (20 g.) and thiocarbonyl chloride were heated as described above, and the residues extracted with just sufficient boiling absolute alcohol to effect solution. The united extracts were cooled, and the deposited crystals filtered off, washed with alcohol, and recrystallised from glacial acetic acid, NN′N″-*triphenylpararosaniline hydrochloride* being obtained as a brown crystalline powder (10—12 g.) (Found: C, 80·8; H, 5·5; Cl, 5·9. $C_{37}H_{30}N_3Cl$ requires C, 80·4; H, 5·4; Cl, 6·4%), soluble in hot acetone, alcohol, glacial acetic acid, and boiling aniline or nitrobenzene, but insoluble in water, ether, chloroform, or benzene.

Nitration of (IV).—Fuming nitric acid (12 ml.) was added slowly to the red compound (5 g.) in glacial acetic acid (25 ml.). The mixture was warmed on the water-bath for 10 minutes; reaction then proceeded without the aid of external heat. The resultant orange solution was poured into water (250 ml.), *pp*′-dinitro-*N*-nitrosodiphenylamine (7·5 g.) being obtained. When this substance (3·5 g.) and aniline (15 ml.) were heated at 120° for ½ hour, and the resultant solution poured into cold 5% hydrochloric acid (200 ml.), *pp*′-dinitrodiphenylamine (1·5 g.) was formed; recrystallised from alcohol, it had m. p. 215°.

Sulphonation of (IV).—The dye (15 g.) was heated to 70° with concentrated sulphuric acid (100 ml.) until solution was complete, and the still warm solution poured on ice. The product, washed with water and recrystallised from alcohol, formed deep red, small crystals with a green reflex (12 g.). Analysis showed that they probably consist of a mixture of the monosulphonic acid and the sulphate of the dye base.

Formation of S-p-*Dimethylaminophenyltrichloromethylthiol and Crystal-violet.*—Dimethylaniline (40 g.) was stirred mechanically, and thiocarbonyl tetrachloride (20 g.) gradually added, the temperature being kept below 20°. After 24 hours, the dark mass was heated at 60° for 3 hours with stirring, and the product extracted with water (250 ml.) at 60° and immediately cooled to 0°. Concentrated hydrochloric acid (10 ml.), added slowly with vigorous stirring, precipitated a substance which, after being collected and washed with water, formed a black crystalline mass. Recrystallisation from ligroin (charcoal) gave S-p-*dimethylaminophenyl-*

trichloromethylthiol (12 g.) in large colourless prisms, m. p. 71°, with a characteristic odour (Found : S, 11·8; Cl, 39·2; *M*, 280. $C_9H_{10}NCl_3S$ requires S, 11·8; Cl, 39·4%; *M*, 270·5). It formed a *dinitro*-derivative, yellow needles, m. p. 123°, from alcohol (Found : Cl, 28·8. $C_9H_8O_4N_3Cl_3S$ requires Cl, 29·2%), and a *monobromo*-derivative, orange-yellow plates, m. p. 146° (decomp.), from glacial acetic acid (Found : S, 9·1. $C_9H_9NCl_3BrS$ requires S, 8·8%). The hydrochloride, from the base in ligroin with dry hydrogen chloride, formed white needles, m. p. 129—130° (decomp.), completely hydrolysed by water to the original base.

The dye in the filtrate from the previous preparation was precipitated by gradual addition of saturated brine; yield, 12 g. Recrystallisation from water gave crystal-violet ($8H_2O$) in long prisms with a bronze reflex; leuco-base, needles from alcohol, m. p. 172°.

The analogous p-*diethylamino-thiol* formed colourless needles, m. p. 44° (Found : S, 11·0; Cl, 35·6. $C_{11}H_{14}NCl_3S$ requires S, 10·7; Cl, 35·7%), but the methylethyl, di-*n*-propyl, and di-*n*-butyl analogues separated as black viscous oils which could not be crystallised.

p-*Dimethylaminophenylthiol*.—*p*-Dimethylaminophenyltrichloromethylthiol (5 g.) and water (200 ml.) were heated under reflux for 3 hours, the mixture made alkaline with sodium hydroxide solution, and the thiol distilled in steam. *p*-Dimethylaminophenylthiol collected as a pale yellow solid, m. p. 32°, which gave a blood-red salt with lead acetate and rapidly oxidised in air to *bis*-(p-*dimethylaminophenyl*) *disulphide*, yellow needles, m. p. 118° (Found : S, 21·3. $C_{16}H_{20}N_2S_2$ requires S, 21·05%), from alcohol; mixed m. p. with an authentic specimen (m. p. 117·5°) prepared from sulphur monochloride and dimethylaniline, 117°.

S-(p-*Dimethylaminophenyl*)-NN′-*diphenyl*iso*thiocarbamide* (VI; R = Ph).—*S*-*p*-Dimethylaminophenyltrichloromethylthiol (10 g.) was added in small portions to aniline (18 g.) in alcohol (200 ml.), and the whole heated on the water-bath for 15 minutes. The iso*thiocarbamide* crystallised on cooling; it formed long glistening needles (11·5 g.), m. p. 175°, from ethyl acetate (Found : S, 9·5. $C_{21}H_{21}N_3S$ requires S, 9·2%). The *di*-p-*tolyl* analogue formed white needles, m. p. 142° (Found : S, 8·7. $C_{23}H_{25}N_3S$ requires S, 8·5%), the *di*-p-*chlorophenyl* analogue glistening plates, m. p. 157° (Found : S, 7·7; Cl, 17·4. $C_{21}H_{19}N_3Cl_2S$ requires S, 7·7; Cl, 17·1%), and the p-*bromophenyl* analogue glistening plates, m. p. 167° (Found : S, 6·5; Br, 31·6. $C_{21}H_{19}N_3Br_2S$ requires S, 6·2; Br, 31·7%).

The p-*diethylamino*-compound formed colourless prisms, m. p. 128° (Found : S, 8·9. $C_{23}H_{25}N_3S$ requires S, 8·5%), and the p-*di*-n-*propylamino*-compound glistening needles, m. p. 125° (Found : S, 8·1. $C_{25}H_{29}N_3S$ requires S, 7·9%), both from ligroin.

Reactions of the iso*Thiocarbamide* (VI; R = Ph).—(i) *With ammonia*. *S*-(*p*-Dimethylaminophenyl)-*NN*′-diphenyl*iso*thiocarbamide (4 g.) and alcoholic ammonia (10 ml.) were heated for 2 hours at 120°. After being freed from ammonia in a vacuum at 15°, the resultant alcoholic solution gave the following tests : (*a*) lead acetate gave a blood-red salt; (*b*) alcoholic mercuric chloride produced an orange precipitate; (*c*) the solution in dilute sodium hydroxide gave a purple colour with sodium nitroprusside; (*d*) hydrogen peroxide gave bis-(*p*-dimethylaminophenyl) disulphide, yellow needles, m. p. 118°, from alcohol; mixed m. p. with an authentic specimen 118° (Found : S, 21·3%). The filtrate from the disulphide was evaporated to dryness, and the residue crystallised from water. Diphenylguanidine separated in colourless leaflets, m. p. 147° (perchlorate, white needles, m. p. 162°).

(ii) *With aniline*. The same *iso*thiocarbamide (2 g.), aniline (0·5 g.), and alcohol (10 ml.) were heated at 170° for 2 hours. The *p*-dimethylaminophenylthiol which was formed rapidly oxidised to the disulphide, which formed yellow needles, from alcohol, m. p. and mixed m. p. 118°. The filtrate from the disulphide, on evaporation, gave triphenylguanidine (colourless needles from alcohol, m. p. 143°; picrate, yellow needles, m. p. 179°).

Preparation of (VI; R = Ph) *from Carbodiphenyldi-imide Monohydrochloride*.—Thiocarbanilide (20 g.) in benzene (250 ml.) at 40° was vigorously stirred, and freshly precipitated mercuric oxide (30 g.) added slowly. After ½ hour, the solution was filtered and the solvent evaporated, leaving carbodiphenyldi-imide as a viscous oil. Dry hydrogen chloride, passed into the solution of this product in ligroin (50 ml.) at 0°, precipitated the monohydrochloride, m. p. 90—92°, free from the dihydrochloride.

Bis-(*p*-dimethylaminophenyl) disulphide (10 g.) was boiled with alcohol (100 ml.) and potassium hydroxide (20 g.) for ½ hour. Glacial acetic acid (17 g.) was added to the cold solution, and the above monohydrochloride was then added slowly, the whole being finally warmed on the water-bath for 15 minutes. The *iso*thiocarbamide (VI; R = Ph) and unchanged disulphide separated on cooling; the former was obtained by fractional recrystallisation from alcohol as glistening needles (1 g.), m. p. 175°, undepressed on admixture with the product obtained from *S*-*p*-dimethylaminophenyltrichloromethylthiol.

Formation of NN'N''-*Triphenylpararosaniline Hydrochloride and the Compound* (IV).—*S*-*p*-Tolyltrichloromethylthiol (5 g.) and diphenylamine (8 g.) were heated at 150° for 4 hours. The cooled melt was washed with ether (50 ml.) and extracted with acetone (100 ml.), and the cooled extract filtered. The residue was washed with benzene (100 ml.), affording *NN'N''*-triphenylpararosaniline hydrochloride (1·5 g.) in small crystals with a copper reflex. The filtrate was poured into pure dry ether (500 ml.), and after standing for 1 hour, the precipitate was collected, washed with ether, and dried in a vacuum. The product, a crystalline solid (1 g.) with a green reflex, had the properties previously described for compound (IV). The absorption spectra of the two compounds in alcoholic solution, measured with a Hilger industrial spectrophotometer, were identical.

Formation of Crystal-violet.—Aluminium chloride (5 g.) was added during 15 minutes to a stirred mixture of *S*-*p*-tolyltrichloromethylthiol (5 g.) and dimethylaniline (7·5 g.), and the product warmed on the water-bath for ½ hour. Thio-*p*-cresol, m. p. 43°, and the excess of dimethylaniline were distilled in steam, and the dye (1·5 g.) precipitated from the cooled solution by addition of saturated brine solution (leuco-base, m. p. 172°).

NN'N''-*Triphenyl*-NN'N''-*trimethylpararosaniline Hydrochloride.*—Diphenylmethylamine (15 g.) and thiocarbonyl tetrachloride (5 g.) were heated at 100° for ½ hour and for a further hour at 120—130°; hydrogen chloride was evolved. The product, after cooling, was washed with ether (50 ml.) and dissolved in acetone (150 ml.), and the cold solution poured into pure dry ether (500 ml.). The precipitate was washed with ether and dried in a vacuum, giving the dye *hydrochloride* (9 g.) as a brown, crystalline solid with a yellowish-green reflex (Found: Cl, 6·2. $C_{40}H_{36}N_3Cl$ requires Cl, 6·0%).

Hexaphenylpararosaniline Hydrochloride and Hexaphenyltriaminotriphenylcarbinol.—Triphenylamine (6·4 g.) and thiocarbonyl chloride (2 g.) were heated at 180° for 2 hours. The product, washed with boiling ether (25 ml.), was extracted with boiling acetone (200 ml.), and the extract filtered. Evaporation of the solvent gave hexaphenylpararosaniline hydrochloride as a deep blue mass with a red metallic lustre, easily soluble in acetone or alcohol. Ammonia precipitated from the alcoholic solution *hexaphenyltriaminotriphenylcarbinol*, which was soluble in benzene and reprecipitated on addition of alcohol (Found: C, 86·4; H, 6·0. $C_{55}H_{43}ON_3$ requires C, 86·7; H, 5·6%). The carbinol was soluble in concentrated sulphuric acid with a blue-violet colour, changing to pure blue on addition of alcohol; water produced a blue precipitate.

Reaction between Tribenzylamine and Thiocarbonyl Tetrachloride.—The amine (15 g.) and the tetrachloride (10 g.) were heated at 100°. Thiocarbonyl chloride (3 g.) distilled as a red liquid, b. p. 72°, and by warming with an excess of aniline gave thiocarbanilide (white plates, m. p. 152°, from alcohol). Extraction of the residue with ether gave benzyl chloride (3·5 g.), b. p. 179° (*p*-nitro-derivative, m. p. 71°). *p*-Bromo-dimethyl- and -diethyl-aniline, dimethyl-*p*-toluidine, and bis-(*p*-dimethylaminophenyl)methane react analogously.

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342. *Compounds of* p-*Nitrodiphenyl Sulphide and of* p-*Nitrodiphenyl Ether with Sulphuric Acid. An Example of Thioquinonoid Formation.*

By HERBERT H. HODGSON and REGGIE SMITH.

Cryoscopic investigation has revealed that *p*-nitrodiphenyl sulphide in concentrated sulphuric acid forms two thionium salts of quinonoid character. In comparison therewith *p*-nitrodiphenyl ether affords a single compound. The compounds, however, were not isolated or analysed. In solution in excess of their aromatic constituents some polymerisation of the compounds to double molecules appears to occur. In excess of sulphuric acid, however, association does not take place.

THE pronounced red colour produced by nitro-aryl sulphides with concentrated sulphuric acid has long been known, and the present cryoscopic investigation was undertaken to ascertain whether these colours are due to compound formation with consequent rearrangement to quinonoid structures. The compound selected was *p*-nitrodiphenyl sulphide, and for purposes of comparison the work was extended to *p*-nitrodiphenyl ether.

From the freezing-point diagram (Fig. 1) it appears that this sulphide forms two compounds, $(NO_2\cdot C_6H_4\cdot S\cdot C_6H_5)_2,H_2SO_4$ (f. p. 51·7° ± 0·1°) and $NO_2\cdot C_6H_4\cdot S\cdot C_6H_5,H_2SO_4$ (f. p. 50·3° ± 0·1°), whereas the ether affords only one compound, $NO_2\cdot C_6H_4\cdot O\cdot C_6H_5,H_2SO_4$ (f. p. 51·8° ± 0·1°), thereby resembling nitrobenzene (Masson, J., 1931, 3200). Unlike the last compound, however, the sulphide and the ether give salts having freezing points lower than those of the aromatic constituents.

FIG. 1.

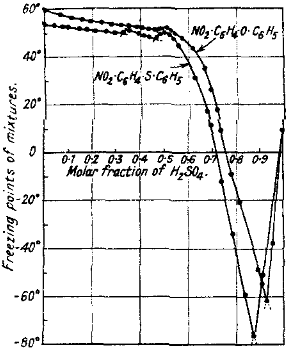
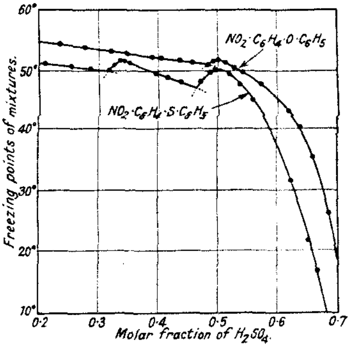
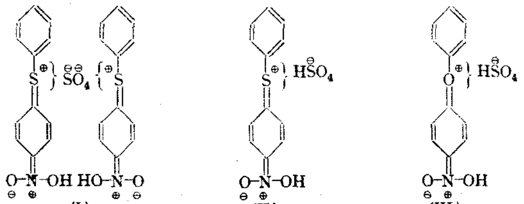


FIG. 2.



To account for the intense colour changes produced, and also because the compounds are electrolytes, the following structural formulæ are proposed, in which the sulphur and the oxygen function in their basic sulphonium (thionium) and oxonium states, respectively. The fact that *p*-nitrodiphenyl sulphide forms both a normal (I) and an acid (II) salt, would appear to indicate that sulphur in the thioquinonoid–thionium condition is more strongly basic than its quinonoid–oxonium analogue (III).



(I.) (II.) (III.)

The compounds themselves were not isolated, but when the various mixtures containing them were diluted with water, the aromatic generators were precipitated with unchanged m. p.

In order to bring about dissolution, it was necessary in some cases, especially where the sulphide and the ether were in excess, to heat the mixture cautiously. The deleterious effect of this heating was investigated for particular mixtures by making a succession of freezing-point determinations at intervals of 5 minutes : generally, after three readings, the freezing point gradually declined and finally became steady at about 5° below the first value ; it then remained constant for several days. When these mixtures were heated on the water-

bath during 15 minutes, the colour gradually changed from the original deep red to a very dark green (almost black), which may be due to sulphonation or carbonisation or both. To avoid any such complications, fresh mixtures were made up for each determination, and their freezing points observed as soon as practicable after complete dissolution had been effected. The melting appeared to be accompanied by much reversible dissociation.

With excess of *p*-nitrodiphenyl sulphide and also of the ether, eutectics were formed at 50·2° and 48·2° for the former and 51·0° for the latter, *i.e.*, only 1·5°, 2·1°, and 0·8° below the freezing points of the compounds, but with excess sulphuric acid they were very pronounced at − 78° and − 62° respectively.

The molecular-depression constants were found to be *ca.* 107° for *p*-nitrodiphenyl sulphide, and *ca.* 130° for *p*-nitrodiphenyl ether, *p*-dichlorobenzene being used as solute. Application of these data to the earlier depression readings, where the curves are linear, shows that the complexes $[(NO_2{\cdot}C_6H_4{\cdot}S{\cdot}C_6H_5)_2,H_2SO_4]_n$ and $[NO_2{\cdot}C_6H_4{\cdot}O{\cdot}C_6H_5,H_2SO_4]_n$ have $n = ca.$ 2·0 in each case, indicating some polymerisation to double molecules. In excess of sulphuric acid, however, the compounds are not polymerised.

Experimental.

Materials.—*p*-Nitrodiphenyl sulphide was prepared by acting on sodium thiophenoxide with excess of *p*-chloronitrobenzene, steam-distilling the product to remove excess of the latter, and finally crystallising it thrice from glacial acetic acid. The pale yellow crystals obtained had m. p. 54·5° (Kehrmann and Bauer, *Ber.*, 1896, **29**, 2364, give m. p. 55·0°; Bourgeois and Huber, *Rec. trav. chim.*, 1912, **31**, 141, give m. p. 54·4°) (Found: N, 6·1; S, 13·9. Calc.: N, 6·0; S, 13·8%).

p-Nitrodiphenyl ether was prepared by heating a mixture of *p*-chloronitrobenzene (1 part), potassium phenoxide (2 parts), and phenol (2 parts) at 150° for 5 hours under reflux. The product was purified as for the sulphide and obtained in very pale yellow crystals, m. p. 60·0° (Haeussermann and Teichmann, *Ber.*, 1896, **29**, 1446, give m. p. 61·0°) (Found: N, 6·6. Calc.: N, 6·5%).

Both products were kept over sulphuric acid in a vacuum desiccator for the stock used for the mixtures.

The sulphuric acid was made by adding the calculated amount of 26% oleum to the ordinary pure concentrated acid, stirring the externally ice-cooled mixture, removing the crystals by filtration through an externally cooled Buchner funnel, remelting the crystals, and repeating the whole process; f. p. 9·6°, *d* 1·8435; the concentration (estimated gravimetrically) was 99·56% of H_2SO_4.

Freezing Points.—The mixtures were made up by weight, with air access only at the beginning of each experiment, and the stirring was performed by a spiral of platinum wire, worked by an electromagnetic device. This method proved to be much superior to that of agitation by a current of air, dried by passage through acid from the stock used for the mixtures, for the efficiency

Cryoscopic Data.

(i) $NO_2{\cdot}C_6H_4{\cdot}S{\cdot}C_6H_5$.						(ii) $NO_2{\cdot}C_6H_4{\cdot}O{\cdot}C_6H_5$.					
N.	F. p.	*N.*	F. p.	*N.*	F. p.	*N.*	F. p.	*N.*	F. p.	*N.*	F. p.
0·000	54·5°	0·335	51·7°	0·555	45·2°	0·000	60·0°	0·433	51·8°	0·659	35·5°
0·034	53·8	0·339	51·6	0·561	43·0	0·061	58·0	0·454	51·3	0·689	26·5
0·074	53·0	0·349	51·3	0·621	31·7	0·110	56·2	0·478	51·0	0·710	18·5
0·091	52·5	0·394	49·6	0·667	17·0	0·151	55·6	0·490	51·6	0·731	9·2
0·144	51·7	0·410	49·0	0·696	11·9	0·188	55·0	0·499	51·8	0·775	− 9·5
0·175	51·3	0·432	48·7	0·741	−12·6	0·233	54·5	0·510	51·5	0·812	−20·6
0·208	51·1	0·469	48·3	0·784	−34·0	0·278	53·8	0·512	51·2	0·890	−48·6
0·253	50·7	0·489	49·8	0·846	−59·0	0·319	53·1	0·524	50·5	0·905	−54·0
0·287	50·2	0·495	50·2	0·870	−76·4	0·344	52·8	0·538	49·9	0·925	−61·8
0·316	50·3	0·518	49·6	0·919	−50·8	0·386	52·3	0·570	48·0	0·949	−38·0
0·323	50·7	0·532	47·9	1·000	9·6	0·401	52·2	0·615	43·6	0·982	− 4·6
						0·431	51·8	0·635	40·6	1·000	9·6

declined with increase of viscosity. Temperatures over the range 10·0—60·0° were measured by an ordinary standardised thermometer to an accuracy of ± 0·05°, and from 10·0° to − 80·0° by a standardised pentane thermometer to an accuracy of ± 0·1°; and were checked by means of measurements with a copper–constantan thermocouple made immediately after the thermometer reading. Solid carbon dioxide (" drikold ") was used to obtain low temperatures. Every pre-

caution was taken to prevent access of moisture to the apparatus, which was also shielded from irregular air currents.

The " freezing point " adopted in these experiments was the highest temperature which the mixture attained after slight supercooling. Several determinations were made, from which it was established that the freezing point could be reproduced with an accuracy of $\pm$ 0·1°.

The data are shown in the foregoing table, in which N represents the molar fraction of sulphuric acid, and the freezing points are corrected values. The diagram (Fig. 2) illustrates the nature of the curves in the region of the compound formation, the actual points being denoted by dots.

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TECHNICAL COLLEGE, HUDDERSFIELD. [*Received, March 17th*, 1937.]

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343. *The Kinetics of the Aldol Condensation.*

By R. P. BELL.

The condensation of acetaldehyde to aldol has been investigated in dilute aqueous solutions of sodium hydroxide (0·0005—0·03N), a dilatometric method being used. After correction for the slow further condensation of the aldol, the reaction is of the first order with respect to acetaldehyde. It is suggested that the slow rate-determining step is the formation of free acetaldehyde from the hydrate $CH_3\cdot CH(OH)_2$, this reaction being catalysed both by hydroxyl ions and by water molecules. The dependence of the reaction velocity on the hydroxyl-ion concentration agrees with this hypothesis. Experiments with solutions of sodium carbonate show that the catalytic power of these solutions is due to their content of hydroxyl ions.

ALL aliphatic aldehydes with a hydrogen atom on the α-carbon atom will undergo the aldol condensation according to the scheme

$$2 \mathrm{>CH{\cdot}CHO} \longrightarrow \mathrm{>CH{\cdot}CH(OH){\cdot}\overset{|}{\underset{|}{C}}{\cdot}CHO}$$

The reagents used to bring about this condensation are all basic, but no work has been done on the kinetics of the catalytic reaction involved, although Usherwood (*J.*, 1923, **123**, 1717) has shown that condensation of *iso*butaldehyde takes place at a measurable rate in saturated sodium carbonate solution.

The present work deals chiefly with the condensation of acetaldehyde in solutions of sodium hydroxide between 0·0005 and 0·03N. It was therefore necessary to prepare solutions of acetaldehyde as far as possible free from acetic acid, and to protect them against oxidation by atmospheric oxygen. In the procedure finally adopted, freshly distilled acetaldehyde was mixed with an equal volume of air-free water, and a current of nitrogen passed first through this solution and then through a cooled flask containing air-free water. The solution obtained in the second flask contained only 1×10^{-4}—1×10^{-3} equiv. of acid per equiv. of acetaldehyde. These solutions were stored under nitrogen, and all transfers were carried out in a current of that gas. The acid concentration of the acetaldehyde solution used was determined before each experiment, and the necessary correction applied to the hydroxyl-ion concentrations.

The aldehyde content of the solutions was determined through the bisulphite compound by the method of Friedman, Cotonio, and Shaffer (*J. Biol. Chem.*, 1927, **73**, 342). This titration should serve in principle as a method for following the kinetics of the aldol condensation, in which the number of aldehyde groups present is halved. It was not, however, found convenient as an accurate method, partly because the reactions are too fast, and partly because elaborate precautions are required to prevent loss of acetaldehyde through the vapour phase and formation of acid by oxidation. The titration method was therefore used only to establish the fact that the main reaction taking place does, in fact, involve the disappearance of half the number of aldehyde groups present, and as a rough confirmation of the reaction velocity derived from the more accurate dilatometric measurements. This is illustrated by Table I, which compares the observed titres with those calculated from the dilatometric curve.

Density determinations with dilute solutions showed that the conversion of acetaldehyde into aldol in aqueous solution results in a contraction of about 50 c. mm. per g., so the reaction may be conveniently followed dilatometrically. (The conversion of acetaldehyde into either crotonaldehyde or paraldehyde is accompanied by an *expansion* in aqueous solution, and could thus be readily distinguished from the aldol condensation.) The dilatometer used had a volume of 31 c.c. and a capillary of 0·233 sq. mm. cross section. The thermostat temperature was 25° ± 0·005°. In carrying out an experiment, a mixture of acetaldehyde solution and air-free water was brought to thermostat temperature, and the reaction started

TABLE I.

0·337M-Acetaldehyde; 0·0071N-sodium hydroxide.

Time, mins.		0	0·5	1·5	3·0	5·0	7·0	9·0	11·0	13·0	15·0	20·0	30·0
Titre, c.c. of N/10-iodine	obs.	13·5	13·05	12·8	12·45	11·45	11·5	10·55	10·0	9·75	9·45	8·45	7·9
	calc.	—	13·05	12·9	12·3	11·7	11·2	10·8	10·15	9·7	9·35	8·7	7·8

by adding a small quantity of N/10-sodium hydroxide solution from a micro-burette. The reaction mixture was then immediately transferred to the dilatometer (previously filled with nitrogen) and forced up into the capillary by nitrogen under pressure. Reliable readings could be obtained 2—3 minutes after mixing. Since the acetaldehyde solution was saturated with nitrogen, the water used was de-aerated shortly before use in order to avoid the formation of bubbles during the experiment. The height of the meniscus was read to the nearest 0·1 mm., and 30—50 readings were taken in each experiment.

It was found that the course of each experiment corresponded very nearly to that of a first-order reaction, and that the change of volume with time could be expressed within the experimental error by an equation of the form (1), where V_0 is the volume at time $t = 0$, k_1^* the

$$V_0 - V = A(1 - e^{-k_1^* t} + \beta t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

velocity constant of the first-order reaction, and βt a correction term; β was throughout about 3% of k_1^*, so that for values of t greater than about 10 times the half-time of the first-order change the volume change was linear with time. This linearity persisted up to at least 20 times $t_{\frac{1}{2}}$, so the value of βA could be determined directly from this linear portion. The observed readings for the earlier stages of the reaction were then corrected by an amount $-\beta At$, and the first-order constant obtained by treating the corrected values according to the method of Guggenheim (*Phil. Mag.*, 1926, **2**, 540); A, the total volume change of the first-order reaction, was obtained by extrapolation to zero time. Table II compares the observed and calculated values for a typical experiment, the latter being given by equation (1) with $A = 106·4$ (expressed in mm. of the dilatometer scale), $k_1^* = 0·0611$, $\beta = 0·00173$.

TABLE II.†

0·0351M-Acetaldehyde; 0·0069N-sodium hydroxide.

Time (mins.).	$V_0 - V$ (mm.). Obs.	Calc.	Time (mins.).	$V_0 - V$ (mm.). Obs.	Calc.	Time (mins.).	$V_0 - V$ (mm.). Obs.	Calc.	Time (mins.).	$V_0 - V$ (mm.). Obs.	Calc.
4	23·3	23·7	16	69·5	69·3	28	92·0	92·3	40	104·8	104·6
6	33·1	33·7	18	74·2	74·2	30	94·8	95·0	60	116·8	117·2
8	42·4	42·6	20	78·7	78·7	32	97·1	97·2	80	123·8	123·8
10	50·6	50·5	22	82·5	82·5	34	99·2	99·4	100	127·5	128·2
12	57·7	57·4	24	86·0	86·4	36	101·2	101·3	120	131·9	131·9
14	64·0	63·7	26	89·1	89·5	38	103·1	102·9	140	135·9	135·9

† For the sake of brevity this table contains only alternate observed readings.

TABLE III.

[Me·CHO].	[NaOH].	10^3k.	$10^3\beta$.	A.	ΔV.	[Me·CHO].	[NaOH].	10^3k.	$10^3\beta$.	A.	ΔV.
0·176	0·0069	24·7	1·19	55	55	0·362	0·00310	14·5	0·80	102	55
0·351	0·0069	26·5	1·85	106	53	0·362	0·0047	18·6	1·20	101	55
0·528	0·0068	26·6	2·45	167	56	0·351	0·0069	26·5	1·74	106	53
0·703	0·0067	26·0	3·60	222	55	0·351	0·0108	38·3	2·56	102	52
						0·351	0·0134	44·6	2·84	111	55
0·362	0·00047	§2·47	—	—	—	0·337	0·0171	55·7	4·13	97	52
0·362	0·00135	§6·70	—	—	—	0·351	0·0206	65·8	5·04	104	53
0·362	0·00140	§7·68	—	—	—	0·343	0·0280	87·5	6·26	96	51

§ See p. 1640.

The results obtained with different concentrations of acetaldehyde and sodium hydroxide are in Table III. The values of k refer to decadic logarithms and are therefore related to k_1^* by the equation $k = 0{\cdot}434k_1^*$, the time being measured in minutes. In the three slowest experiments it was not convenient to measure β directly, and in calculating k the observed readings were corrected on the assumption that the value of the ratio k/β is the mean of the values for the other experiments; A is in mm. of the dilatometer scale, and ΔV represents the same volume converted into c. mm. and referred to 1 g. of acetaldehyde.

The form of equation (1) probably represents two consecutive irreversible first-order reactions, the second being much slower than the first. This may be shown by reference to the general case

$$M_1 \xrightarrow[k_1]{} M_2 \xrightarrow[k_2]{} M_3$$

the total volume of the solution being given by

$$V = A_1[M_1] + A_2[M_2] + A_3[M_3] + B$$

where A_1, A_2, A_3, and B are constants. If a_1 is the initial concentration of M_1, and V_0 the initial volume, the change of volume with time is given exactly by

$$V_0 - V = a_1\left\{A_1 - A_3 - e^{-k_1t}\left(A_1 - \frac{A_2k_1 - A_3k_2}{k_1 - k_2}\right) - e^{-k_2t}\,\frac{k_1\,(A_2 - A_3)}{k_1 - k_2}\right\} \quad . \quad (2)$$

If $k_1 \gg k_2$ and $t \ll 1/k_2$, this reduces to

$$V_0 - V = a_1\,\{(A_1 - A_2)(1 - e^{-k_1t}) + k_2t\,(A_2 - A_3)\} \quad . \quad . \quad . \quad . \quad (3)$$

identical in form with (1).

Apart from the exact significance of the linear correction term in (1), it is clear that the main reaction taking place is a first-order change characterised by the velocity constant k_1^* (or k in Table III) and the total volume change A. The order of this reaction is further confirmed by the first four experiments in Table III, which show that for a constant hydroxyl-ion concentration the value of k is independent of the acetaldehyde concentration. Comparison with the titration results (cf. Table I) serves to identify this main reaction with the formation of aldol, and the contraction per g. of aldehyde (col. 6 in Table III) agrees well with that calculated from the densities of solutions of acetaldehyde and aldol. The subsequent slow contraction is probably due to further condensation of the aldol to give dialdan or similar products, since the formation of crotonaldehyde (or paraldehyde) would be accompanied by an *increase* of volume. This agrees with the fact that the aldehyde titre falls slightly below 50% of the initial value during the second slow stage of the reaction. It may be mentioned that the solutions remained colourless during the period covered by the measurements, but were slightly yellow on the following day.

It is surprising that the condensation of two acetaldehyde molecules to one of aldol should be kinetically of the first order. This can be accounted for by the scheme

$$\left.\begin{array}{lll}
(a) & CH_3{\cdot}CHO \rightleftarrows X & \text{(slow)} \\
(b) & X + CH_3{\cdot}CHO \searrow & \\
 & \qquad\qquad CH_3{\cdot}CH(OH){\cdot}CH_2{\cdot}CHO & \text{(fast)} \\
\text{or} & 2CH_3{\cdot}CHO \nearrow &
\end{array}\right\} \quad (4)$$

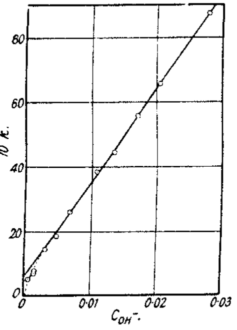
where X is any product formed from one molecule of acetaldehyde. It is suggested that the slow unimolecular process (a) may be the dehydration of hydrated acetaldehyde (ethylidene glycol), the reaction scheme then becoming

$$\left.\begin{array}{ll}
(a) \quad CH_3{\cdot}CH(OH)_2 \rightleftarrows CH_3{\cdot}CHO + H_2O & \text{(slow)} \\
(b) \quad CH_3{\cdot}CH(OH)_2 + CH_3{\cdot}CHO \longrightarrow CH_3{\cdot}CH(OH){\cdot}CH_2{\cdot}CHO + H_2O & \text{(fast)}
\end{array}\right\} \quad (5)$$

There is much evidence to show that in dilute aqueous solutions of aldehyde the equilibrium (a) is far over on the left-hand side, the amount of free aldehyde present being very small. Moreover, both density measurements (Perkin, J., 1887, **51**, 808) and calorimetric measurements (Brown and Pickering, J., 1897, **81**, 756) show that this equilibrium is not set up instantaneously, and in the latter case it was also established that the change is accelerated

by hydroxyl ions. The second stage (*b*) might involve two unhydrated acetaldehyde molecules, but the scheme given above seems more probable in view of the fact that the aldol condensation appears to require the presence of water.

The figure shows the dependence of the velocity constant *k* upon the hydroxyl-ion concentration. With the exception of the three lowest points, the results are well represented by a straight line cutting the velocity axis above the origin. This indicates that the rate-determining process is catalysed not only by hydroxyl ions but also by water molecules; *i.e.*, there is a "spontaneous" reaction. This accords with the known facts about the hydration equilibrium of acetaldehyde. The straight line cannot, however, represent the velocity of the actual aldol condensation right down to $C_{OH'} = 0$, since the velocity becomes zero at zero hydroxyl-ion concentration. (Slightly acid solutions of acetaldehyde can be kept for several months at room temperature without any detectable change in aldehyde titre.) The three lowest points lie below the straight line, and the complete velocity–concentration curve must follow the course indicated roughly by the broken line. This behaviour can be accounted for on the basis of the above scheme if it is assumed that the second stage (*b*) is catalysed by hydroxyl ions only, its velocity becoming zero when $C_{OH'} = 0$. With decreasing hydroxyl-ion concentration a point will be reached at which the velocity of (*b*) is no longer great compared with that of (*a*), and in sufficiently dilute solutions the second-order reaction (*b*) will eventually become the rate-determining step. This explanation is supported by the fact that the three slowest reactions (marked with a section in Table III) are not strictly unimolecular, the velocity falling off too rapidly with time.



The above interpretation assumes the reaction scheme (5), but it will apply equally well to any other assumption about the unimolecular change (*a*); *e.g.*, (*a*) might be the enolisation of the acetaldehyde.

Since the first-order change is catalysed by both hydroxyl-ions and water molecules, other basic species (*e.g.*, the anions of weak acids) might be expected to exert a catalytic effect. However, it is clear from the above that the first-order change can only be investigated in solutions of fairly high hydroxyl-ion concentration, and in these circumstances it will be difficult to detect catalysis by other species. A few experiments were done in solutions of sodium carbonate (which is commonly used as a reagent for effecting the aldol condensation), and it was found that the velocity was indistinguishable from the value in sodium hydroxide solutions of the same hydroxyl-ion concentration. An experiment was also carried out using an 0·5M-acetate buffer of p_H 5·5, but no change could be detected in spite of the high concentration of basic acetate ions: this is accounted for by the absence of hydroxyl ions to catalyse the second stage of the reaction.

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344. *Aconitine. Part II. The Relationship between Aconitine and Atisine and Some Degradation Products of the Latter.*

By Alexander Lawson and James E. C. Topps.

The formula $C_{22}H_{31}O_2N$ for atisine proposed by Wright and by Jowett is not in agreement with the analytical results now reported. The formula $C_{22}H_{33}O_2N$ is preferred.

Atisine has been shown to possess a methylenedioxy- and a methylimido-group,

and to form a dihydro-derivative by catalytic hydrogenation, thus being derived from the fully hydrogenated nucleus $C_{20}H_{33}N$. This would indicate that the carbon skeleton has a pentacyclic structure. This being so, the relationship of atisine to aconitine is not obvious, for on the basis of Freudenberg's work (*Ber.*, 1936, **69**, 1962) aconine, of which aconitine is the benzoyl acetyl derivative, should have a hexacyclic nucleus. Atisine appears, however, to be more closely related to lucidisculine (from *A. lucidisculum*), $C_{24}H_{37}O_4N$ (Majima and Morio, *Ber.*, 1932, **65**, 599).

Some degradation products of atisine are described, a hydrocarbon $C_{17}H_{16}$ and a base $C_{17}H_{17}N$ representing the most far-reaching degradations yet attained.

THE rhizomes of the Indian plant *Aconitum heterophyllum* (Wall.), used in native medicine under the name of atis root, contain an alkaloid atisine, for which the formula $C_{22}H_{31}O_2N$ was proposed by Wright ("Year Book of Pharmacy," 1879, 442). A number of its salts were prepared by Jowett (J., 1896, **69**, 1518), but little investigation of its constitution has till now been attempted. The preliminary examination of the alkaloid and several degradation products are now described; none of the latter have yet been identified.

The material was obtained through the courtesy of Mr. C. C. Calder, B.Sc., Director of the Botanical Survey of India. The alkaloid content of atis root appears to depreciate fairly rapidly on keeping, since unsatisfactory yields were obtained with material which had been bought in the open market in India. The method of extraction was a simplified procedure based on that used by Jowett (*loc. cit.*).

Our analytical results for atisine hydrochloride are not in agreement with the formula $C_{22}H_{31}O_2N$ of Wright and Jowett, but suggest rather $C_{22}H_{33}O_2N$, this being supported by the analysis of the *hydrochloride* of a dihydro-derivative, $C_{22}H_{35}O_2N$, formed by catalytic hydrogenation. Wright's data were obtained by a single analysis of the amorphous aurichloride, and Jowett's, by the analysis of the hydriodide and the nitrate; the hydrogen result for Jowett's first-named compound shows better agreement with the formula suggested here. Chandrasena (J., 1933, 740) claimed to have isolated atisine in crystalline form, and proposed the formula $C_{22}H_{35}O_4N$ in accordance with his analytical results: these, however, are almost identical with those reported here for atisine hydrochloride and it would therefore appear that his so-called crystalline atisine is actually the hydrochloride. Such a view is supported by the result of the determination of chlorine in atisine perchlorate reported by him.

Negative results in Zeisel and Zerewitinoff determinations, and the fact that atisine gives a precipitate with Gaebel's phloroglucinol–sulphuric acid reagent (*Arch. Pharm.*, 1910, **248**, 225), indicate that the two oxygen atoms in the molecule are present in a methylenedioxy-group. No coloration was observed, however, in the corresponding reaction with gallic acid, a fact which may be accounted for on the supposition that the group is not attached to an aromatic ring. An alkylimido-group also is present in atisine. This is probably a methylimide, since the action of potassium ethoxide produced a *base*, $C_{21}H_{31}O_2N$, not containing an alkylimido-group.

The extended formula for atisine is therefore $C_{20}H_{28}(CH_2O_2)(NMe)$ and the parent nucleus is $C_{20}H_{31}N$. Allowance being made for the presence of one double bond in the molecule, as shown by the formation of the dihydro-derivative, and CH_2 being substituted for NH in this formula, the alkaloid may be regarded as derived from the fully hydrogenated hydrocarbon $C_{21}H_{34}$. This, by comparison with the open-chain paraffin $C_{21}H_{44}$, indicates the presence of a pentacyclic system in the molecule.

On this basis, however, the relationship with aconitine is not obvious, because, allowing for the known substituent groups in this molecule, of which $C_{34}H_{47}O_{11}N$ is the accepted formula, the parent nucleus becomes $C_{19}H_{29}N$, as pointed out by Freudenberg (*Ber.*, 1936, **69**, 1962). This differs from atisine in being derived from a hexacyclic system.

Majima and Morio (*Ber.*, 1932, **65**, 599) suggested that there is a close relationship between atisine and lucidisculine (from *A. lucidisculum*). This alkaloid, $C_{24}H_{37}O_4N$, contains an acetyl, a hydroxyl, and a methylimido-group. The nature of the fourth oxygen atom is not known, but it is not likely to be present as hydroxyl, since only a monoacetyl derivative can be obtained. If this oxygen atom be considered as indifferent

and present as a bridge linkage or as a carbonyl group, the parent nucleus becomes $C_{21}H_{35}N$, a formula which points to the alkaloid being derived, as has been suggested for atisine, from a pentacyclic system.

The oxidation of atisine with potassium permanganate or chromic acid, even under the mildest conditions, led to extensive decomposition. By the action of zinc dust, after removal of the methylenedioxy-group, however, a base was obtained involving the loss of one carbon atom only and having the formula $C_{20}H_{31}ON$.

By the dehydrogenation of atisine with selenium, products probably corresponding to different stages in the reaction were isolated. Under mild conditions (at 200°), a base, $C_{20}H_{29}ON$, and a crystalline neutral *substance*, $C_{19}H_{27}O_2N$, were obtained. The base appears to be derived from the alkaloid by loss of the methylimido- and the methylenedioxy-group. Under more vigorous conditions (at 300—320°), these products were partly converted into an oily hydrocarbon, $C_{17}H_{16}$, which was isolated as the picrate and recovered crystalline. The physical characteristics of the derivatives suggest its being a substituted phenanthrene, but comparison of the picrate with those of known alkylphenanthrenes of this formula, and also with those of 4-*n*-propyl- and 4-*iso*propylphenanthrene, which were synthesised by Haworth's method (J., 1932, 1125), failed to disclose its identity. It is being further examined.

By the action of alcoholic potash on atisine, Jowett obtained a compound, isolated as the aurichloride, to which he ascribed the formula $C_{22}H_{31}O_2N,H_2O$. No product has been isolated in this laboratory by this reaction, but by the action of potassium ethoxide a crystalline base, $C_{21}H_{31}O_2N$, was obtained corresponding to the loss of the methyl group attached to the nitrogen atom. This compound could be extensively dehydrogenated without losing its basic character, yielding a derivative, $C_{17}H_{17}N$, which was obtained as the *picrate*. In addition to this base, the hydrocarbon previously obtained by the dehydrogenation of atisine was also formed. The neutral compound was however missing.

Experimental.

Extraction of Atisine.—The finely ground rhizomes were percolated with warm rectified spirit, the alcohol removed under reduced pressure, and the residue taken up with 2% sulphuric acid. Tarry matter and oil were extracted with chloroform, and the base shaken out of the alkaline liquor with ether. Purification was carried out by crystallisation of the hydrochloride from aqueous alcohol. The colourless needles obtained had m.p. 296° (decomp.), and the yield was *ca.* 0·25%. Atisine appears to be the only base in *A. heterophyllum* [Found: C, 69·1, 69·3, 69·2; H, 9·0, 8·9, 9·4; N, 3·3, 3·5, 3·8; Cl, 9·6; OMe, 0; active H, 0; CH_2O_2 (by the method of Clowes and Tollens, *Ber.*, 1899, **32**, 2841), 7·55; NMe, 6·0, 5·4; *M* (by titration with silver nitrate), 381. Calc. for $C_{22}H_{33}O_2N,HCl$: C, 69·6; H, 9·0; N, 3·7; Cl, 9·4; 1 CH_2O_2, 7·9; NMe, 7·65%; *M*, 379·5. $C_{22}H_{31}O_2N,HCl$ would require H, 8·5%].

Hydrogenation of Atisine.—Atisine hydrochloride (1 g.) was dissolved in acetic acid (20 c.c.) and hydrogenated in the presence of palladium-black (0·2 g.); 67 c.c. of hydrogen at 19°/758 mm. were taken up (2H requires 63 c.c.). The solution was freed from palladium, made alkaline, and extracted with ether. The colourless varnish remaining on removal of the ether was converted into the *hydrochloride*, which crystallised from alcohol in colourless needles, m.p. 319° (decomp.) (Found: C, 69·1; H, 9·4; N, 3·6. $C_{22}H_{35}O_2N,HCl$ requires C, 69·1; H, 9·4; N, 3·7%).

Action of Zinc Dust on Atisine.—Atisine, distilled over zinc dust, gave a varnish from which no crystalline product has yet been isolated. Removal of the methylenedioxy-group with hydrochloric acid, previous to the zinc dust treatment, led to the formation of a small amount of an amorphous base, from which a crystalline *picrate* was isolated as needles, m.p. 173° (Found: C, 58·6; H, 6·4; N, 10·4. $C_{20}H_{31}ON,C_6H_3O_7N_3$ requires C, 58·9; H, 6·4; N, 10·6%).

Action of Potassium Ethoxide on Atisine.—Atisine (1 g.) was added to 20% alcoholic potassium ethoxide (30 c.c.), and the mixture boiled for 6 hours. Water was added, and the alcohol evaporated under reduced pressure. After some time crystals separated. These were removed, washed with a little ether, and recrystallised from ethyl acetate, forming colourless plates, m.p. 147° (Found: C, 75·7, 75·8; H, 10·1, 10·5; N, 4·3. $C_{21}H_{31}O_2N$ requires C, 76·5; H, 9·4; N, 4·3%). The *hydrochloride* of this *base* crystallised from aqueous alcohol in needles, m.p. 278° (decomp.) (Found: C, 68·6, 67·0; H, 9·0, 9·1; N, 4·6, 5·0; *M*, 369, 371;

NMe, 0; test for methylenedioxy-group, positive. $C_{21}H_{31}O_2N,HCl$ requires C, 69·0; H, 8·9; N, 3·8%; *M*, 365·5).

Dehydrogenation of Atisine with Selenium.—Atisine (2 g.) was heated with powdered selenium (10 g.) at 300—320° for 10 hours. The tarry material was then extracted (Soxhlet) with ether, from which the basic material was shaken out with dilute hydrochloric acid. The aqueous solution was made alkaline with caustic soda, and the base extracted with ether. On evaporation of the ether, and fractional distillation of the remaining oil, a colourless varnish was obtained, b.p. 190—200°/1 mm. This was converted into the *picrate*, which crystallised from acetone–alcohol in yellow needles, m.p. 242—243° (decomp.) (Found: C, 58·7; H, 6·1; N, 10·1. $C_{20}H_{29}ON,C_6H_3O_7N_3$ requires C, 59·1; H, 6·1; N, 10·6%). The amorphous base regenerated from the purified picrate was converted into the *hydrochloride*, which crystallised from alcohol–ether in clusters of prisms, m.p. 265° (Found: C, 71·5; H, 8·9; N, 4·3; NMe, 0; OMe, 0; methylenedioxy-test, negative. $C_{20}H_{29}ON,HCl$ requires C, 71·5; H, 8·9; N, 4·2%).

The ether containing the neutral substances from the dehydrogenation was removed, and the residue fractionally distilled, giving three fractions: (1) b.p. 130—160°/1 mm., a colourless oil yielding a *picrate*. This was recrystallised from alcohol and formed fine orange needles, m.p. 129° (Found: C, 61·8; H, 4·5; N, 9·0. $C_{17}H_{16},C_6H_3O_7N_3$ requires C, 61·5; H, 4·2; N, 9·35%). The *trinitrobenzene* derivative of the hydrocarbon was also prepared, and formed yellow felted needles, m.p. 140° (Found: C, 63·3; H, 4·55; N, 9·6. $C_{17}H_{16},C_6H_3O_6N_3$ requires C, 63·7; H, 4·4; N, 9·7%). The hydrocarbon recovered from the picrate crystallised from alcohol in colourless plates, m.p. 41°. (2) b.p. 170—200°/1 mm., a viscous brown oil showing a green fluorescence; a crystalline derivative could not be isolated. (3) b.p. above 220°/1 mm., colourless felted needles, m.p. 240°, very soluble in alcohol, sparingly in ether. This *substance* was recrystallised from alcohol–ether (Found: C, 76·05; H, 9·25; N, 4·7. $C_{19}H_{27}O_2N$ requires C, 75·75; H, 9·0; N, 4·65%).

When atisine was dehydrogenated at 200°, the only products which could be isolated were the base $C_{20}H_{29}ON$ and (3). Both of these gave (1) at the higher temperature.

Dehydrogenation with Selenium of the Base obtained from Atisine by the Action of Potassium Ethoxide.—The method was that previously described for the dehydrogenation of atisine. From the ethereal extract of the products two substances were isolated: (1) a base, b.p. 150—160°/1 mm.; this was obtained as a green fluorescent oil, the *picrate* of which crystallised from acetone–alcohol in felted yellow needles, m.p. 206° (Found: C, 59·1; H, 4·3; N, 12·2. $C_{17}H_{17}N,C_6H_3O_7N_3$ requires C, 59·45; H, 4·3; N, 12·1%); (2) the hydrocarbon $C_{17}H_{16}$ previously obtained by the dehydrogenation of atisine.

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345. *Amidines. Part II. Diamidines from Di-imidochlorides derived from Diamines.*

By H. K. S. RAO and T. S. WHEELER.

Diamidines of the types NRR′·CPh:N·C_6H_4·C_6H_4·N:CPh·NRR′ and NRR′·CPh:N·C_6H_4·N:CPh·NRR′ have been prepared.

DI-IMIDOCHLORIDES, from diamines, and the corresponding diamidines have hitherto been unknown. The dibenzoyl derivatives of benzidine and of *m*- and *p*-phenylenediamines have now been converted into the corresponding *di-imidochlorides*, which have been condensed, by Shah's modified method (*J. Indian Inst. Sci.*, 1924, **7**, 215), with a number of amines to yield *diamidines* of the types NRR′·CPh:N·C_6H_4·C_6H_4·N:CPh·NRR′ and NRR′·CPh:N·C_6H_4·N:CPh·NRR′.

Dinitriles also have been obtained from the di-imidochlorides derived from benzidine

and *p*-phenylenediamine, by treating them with potassium cyanide (cf. Mumm, Volquartz, and Hesse, *Ber.*, 1914, **47**, 751).

Dibenzbenzididedi-imidochloride.—A mixture of dibenzoylbenzidine (25 g.), phosphorus pentachloride (30 g.), and nitrobenzene (30 c.c.) was heated under reflux (calcium chloride guard-tube) until a clear liquid was produced. The yellow crystals (22 g.) obtained at room temperature after 12 hours were washed with light petroleum and kept under reduced pressure over phosphoric oxide and paraffin wax for 24 hours; m. p. 212° (Found: Cl, 16·6. $C_{26}H_{18}N_2Cl_2$ requires Cl, 16·6%).

NN'-*Di-(α-o-chloroanilinobenzylidene)benzidine.*—A mixture of the di-imidochloride (5 g.), *o*-chloroaniline (3·2 g.), and diethylaniline (10 c.c.) which had been heated at 100° for 2 hours was poured into excess of dilute hydrochloric acid (1 : 1), and after 2 hours the insoluble hydrochloride was decomposed with concentrated aqueous ammonia at 100°; the *base* crystallised from toluene in yellowish clusters of needles, m. p. 234° (Found: Cl, 11·3. $C_{38}H_{28}N_4Cl_2$ requires Cl, 11·6%). The yellow *picrate* separated slowly from mixed solutions of the base and picric acid in hot chlorobenzene; m. p. 229—230° (decomp.) (Found: Cl, 6·9. $C_{38}H_{28}N_4Cl_2,2C_6H_3O_7N_3$ requires Cl, 6·6%).

The following di-amidines were similarly prepared. They were yellowish in colour and were crystallised from chlorobenzene or toluene: *Di-(α-methylanilinobenzylidene)benzidine*, m. p. 234° (Found: N, 10·1. $C_{40}H_{34}N_4$ requires N, 9·8%); *picrate*, m. p. 248° (decomp.) (Found: N, 13·7. $C_{40}H_{34}N_4,2C_6H_3O_7N_3$ requires N, 13·6%). *Di-(α-ethylanilinobenzylidene)-benzidine*, m. p. 203° (Found: N, 9·6. $C_{42}H_{38}N_4$ requires N, 9·4%); *picrate*, m. p. 235° (decomp.) (Found: N, 13·2. $C_{42}H_{38}N_4,2C_6H_3O_7N_3$ requires N, 13·3%). *Di-(α-benzylanilino-benzylidene)benzidine*, m. p. 174° (Found: C, 86·6; H, 6·2. $C_{52}H_{42}N_4$ requires C, 86·4; H, 5·8%); *picrate*, m. p. 185° (decomp.) (Found: N, 11·8. $C_{52}H_{42}N_4,2C_6H_3O_7N_3$ requires N, 11·9%). *Di-(α-diphenylaminobenzylidene)benzidine*, m. p. 262° (Found: N, 8·6. $C_{50}H_{38}N_4$ requires N, 8·1%); *picrate*, m. p. 234° (Found: N, 11·5. $C_{50}H_{38}N_4,2C_6H_3O_7N_3$ requires N, 12·1%). *Di-(α-ethyl-o-toluidinobenzylidene)benzidine*, m. p. 200° (Found: C, 84·5; H, 6·8. $C_{44}H_{42}N_4$ requires C, 84·4; H, 6·7%). *Di-(α-ethyl-p-toluidinobenzylidene)benzidine*, m. p. 221° (Found: C, 84·2; H, 6·5; N, 8·8. $C_{44}H_{42}N_4$ requires C, 84·4; H, 6·7; N, 8·9%). The picrates separate as oils in the last two cases.

NN'-*Di-(α-aminobenzylidene)benzidine*, obtained by shaking a mixture of the di-imidochloride (20 g.) and a concentrated solution of ammonia in methyl alcohol (150 c.c.) for 48 hours, crystallised from pyridine in yellow needles, m. p. 252° (Found: C, 79·8; H, 5·9; N, 14·0. $C_{26}H_{22}N_4$ requires C, 80·0; H, 5·6; N, 14·3%).

Dibenz-p-phenylenediamidedi-imidochloride was prepared from a mixture of dibenzoyl-*p*-phenylenediamine (50 g.), phosphorus pentachloride (75 g.), and nitrobenzene (40 c.c.), washed with dry light petroleum, and dried as before; m. p. 176° (Found: Cl, 21·0. $C_{20}H_{14}N_2Cl_2$ requires Cl, 20·1%).

The following diamidines were prepared as described above. NN'-*Di-(α-methylanilino-benzylidene)-p-phenylenediamine*, m. p. 264° (Found: N, 10·8. $C_{34}H_{30}N_4$ requires N, 11·3%); *picrate*, m. p. 243° (decomp.) (Found: N, 14·5. $C_{34}H_{30}N_4,2C_6H_3O_7N_3$ requires N, 14·7%). *Di-(α-benzylanilinobenzylidene)-p-phenylenediamine*, m. p. 203° (Found: C, 85·7; H, 6·0; N, 8·9. $C_{46}H_{38}N_4$ requires C, 85·4; H, 5·9; N, 8·7%); *picrate*, m. p. 220° (decomp.) (Found: N, 12·8. $C_{46}H_{38}N_4,2C_6H_3O_7N_3$ requires N, 12·7%). *Di-(α-methyl-o-toluidinobenzylidene)-p-phenylenediamine*, m. p. 227° (Found: C, 82·7; H, 6·7; N, 10·8. $C_{36}H_{34}N_4$ requires C, 82·8; H, 6·5; N, 10·7%); *picrate*, m. p. 236° (decomp.) (Found: N, 13·7. $C_{36}H_{34}N_4,2C_6H_3O_7N_3$ requires N, 14·3%). *Di-(α-ethyl-o-toluidinobenzylidene)-p-phenylenediamine*, m. p. 186° (Found: C, 83·0; H, 6·9. $C_{38}H_{38}N_4$ requires C, 82·9; H, 6·9%); *picrate*, m. p. 237° (decomp.) (Found: N, 14·0. $C_{38}H_{38}N_4,2C_6H_3O_7N_3$ requires N, 13·9%).

When the clear solution obtained by heating a mixture of dibenzoyl-*m*-phenylenediamine (10 g.) and phosphorus pentachloride (14 g.) was cooled, *dibenz-m-phenylenediamidedi-imido-chloride* (6 g.) crystallised in greyish clusters of needles. It was washed with dry light petroleum and dried as usual; m. p. 86° (Found: Cl, 19·5. $C_{20}H_{14}N_2Cl_2$ requires Cl, 20·1%).

Di-(α-benzylanilinobenzylidene)-m-phenylenediamine had m. p. 129—130° (Found: C, 84·8; H, 6·2. $C_{46}H_{38}N_4$ requires C, 85·4; H, 5·9%); the picrate separated as a paste.

NN'-*Di-(α-cyanobenzylidene)benzidine* was obtained by heating a mixture of dibenzbenzidide-di-imidochloride (2·5 g.) and methyl-alcoholic potassium cyanide (2 g. in 100 c.c.) under reflux for about 15 minutes; crystallised from toluene, it had m. p. 252° (Found: C, 82·0; H, 4·6. $C_{28}H_{18}N_4$ requires C, 81·9; H, 4·4%).

NN′-*Di-(α-cyanobenzylidene)*-p-*phenylenediamine*, prepared from dibenz-*p*-phenylenediamide-di-imidochloride as described above and crystallised from toluene, had m. p. 236° (Found: C, 78·6; H, 4·2. $C_{22}H_{14}N_4$ requires C, 79·0; H, 4·2%).

The authors' thanks are due to Dr. R. C. Shah for his valuable advice.

ROYAL INSTITUTE OF SCIENCE, BOMBAY. [*Received, August 12th*, 1937.]

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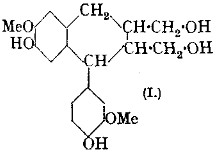
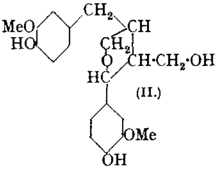
346. *The Constitution of Natural Phenolic Resins. Part IX. The Structure of Lariciresinol and Preliminary Experiments on the Synthesis of Lignandiols.**

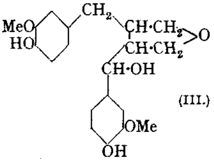
By ROBERT D. HAWORTH and WILLIAM KELLY.

The structures suggested in Part VIII (this vol., p. 384) for lariciresinol and *iso*lariciresinol have been confirmed by new observations. Experiments aiming at the synthesis of lignandiols have, so far, been unsuccessful, but a number of the preliminary experiments, including a new method for the preparation of aryltetronic acids, are now described.

IN Part VIII (this vol., p. 384), structure (I) was advanced for *iso*lariciresinol and of the two alternative formulæ for lariciresinol, (II) was preferred to (III). The *iso*lariciresinol formula (I) has now been confirmed by dehydrogenation of the dimethyl ether with lead tetra-acetate, which yielded the optically inactive *dehydro*-derivative (IV). The structure (II) for lariciresinol was favoured, first because it rendered the lariciresinol–*iso*lariciresinol change analogous to the olivil–*iso*olivil conversion, and secondly because lariciresinol dimethyl ether behaved as a primary alcohol in reacting with phthalic anhydride in boiling benzene solution. The product was an acidic oil and renewed efforts to obtain this in a crystalline state or to prepare crystalline *p*-nitrobenzoyl or *p*-phenylphenacyl derivatives have been unsuccessful.


(I.)


(II.)

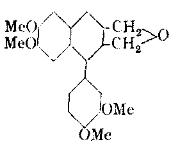

(III.)

A crystalline *triphenylmethyl ether* of lariciresinol dimethyl ether has been prepared by treatment with triphenylmethyl chloride in pyridine solution. Although there are indications that triphenylmethyl chloride may attack the secondary alcoholic group of small molecules such as *iso*propyl alcohol (Helferich, Spiedel, and Toldte, *Ber.*, 1923, **56**, 766), there is evidence (Josephson, *Annalen*, 1929, **472**, 230) suggesting that this reagent combines with the primary alcoholic group only in more complex molecules. When the triphenylmethyl ether of lariciresinol dimethyl ether is boiled with 80% formic acid, the triphenylmethyl group is eliminated, cyclisation occurs, and the *diformyl* derivative of *iso*lariciresinol dimethyl ether is produced. The lariciresinol–*iso*lariciresinol change is difficult to explain on the basis of formula (III) for lariciresinol; the formation of anhydro*iso*lariciresinol derivatives would be anticipated and subsequent hydration to the diol is improbable because it has been shown that anhydro*iso*lariciresinol dimethyl ether is not attacked under the conditions of the isomeric change.

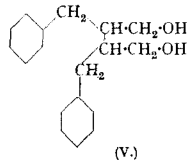
* The generic term lignan has been introduced (*Ann. Reports*, 1936, **33**, 267) to include all members of the bis-coniferyl family.

Methods are now available for the preparation of lactones of the lignan series, but no attempts to synthesise other types have been recorded. Some experiments in this direction have been initiated and the results of the preliminaries are now reported. From a stereochemical point of view, the most attractive route to the lignandiols of types (I) and (V) involves the reduction of lactones of the conidendrin or matairesinol types, but efforts to reduce the ethers of these lactones by means of sodium in ethyl or amyl alcohol, or by the use of aluminium amalgam, have so far been unsuccessful.

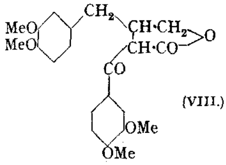
Attempts have been made to employ αβ-dibenzoylethane or its derivatives such as ethyl αβ-dibenzoylpropionate (VI) (Kapf and Paal, *Ber.*, 1888, **21**, 1487) and ethyl αβ-dibenzoylsuccinate (VII) (Knorr, *Annalen*, 1896, **293**, 74; 1899, **306**, 389). The methylene



(IV.)



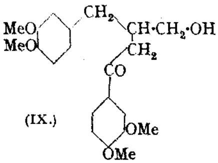
(V.)



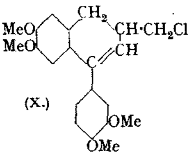
(VIII.)

groups of αβ-dibenzoylethane proved surprisingly unreactive and no condensation occurred with formalin, ethyl formate, or ethyl oxalate. The esters (VI) and (VII) were similarly unreactive, although in the presence of alkaline condensing agents the ester (VI) yielded the lactone of γ-hydroxy-α-benzoyl-γ-phenyl-Δ^{β}-butenoic acid (Kapf and Paal, *loc. cit.*; Borsche and Fels, *Ber.*, 1906, **39**, 1813), whilst in the presence of formalin and a slight excess of alkali, ester (VII) was converted into benzoic acid. The ester (VII) is readily converted by concentrated sulphuric acid into ethyl 2 : 5-diphenylfuran-3 : 4-dicarboxylate (Perkin, J., 1885, **47**, 271), but reduction of either the furan nucleus or the ester groups could not be effected. Similar behaviour has been observed with *αβ-diveratroylethane* and *ethyl αβ-diveratroylpropionate*.

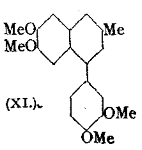
Reaction between O-methyleugenol oxide and reactive methylene groups has previously been observed with malonic, acetoacetic, and cyanoacetic esters, but no reaction has been detected with acetoveratrone, veratroylacetonitrile, ethyl acetylpyruvate, or ethyl veratroylpyruvate. The possibility of utilising α-veratroyl-β-(3′ : 4′-dimethoxybenzyl)butyrolactone (VIII) (J., 1936, 725) has been explored. In cold alkaline solution this lactone (VIII) and formalin yielded veratric acid and a water-soluble product which has not been identified. On the other hand, warm dilute alkali converts (VIII) into *δ-keto-β-hydroxymethyl-αδ-diveratrylbutane* (IX), and a similar ketone has been prepared from the



(IX.)



(X.)

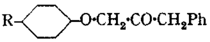


(XI.)

methylenedioxy-analogue of (VIII) (J., **1936**, 747). It has also been observed that benzoylacetone and benzoylacetaldehyde are readily converted into benzoic acid in the presence of cold alkali and formalin, but in the absence of the formalin, acetophenone is the main product of the hydrolysis. It is probable that in all these cases the formalin condenses with the methylene group and facilitates acid hydrolysis in the product (Dieckmann, *Ber.*, **1900**, **33**, 2670).

The action of a mixture of acetic and hydrochloric acids on (IX) resulted in cyclisation to *6 : 7-dimethoxy-1-veratryl-3-chloromethyl-3 : 4-dihydronaphthalene* (X), which, when warmed

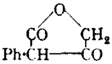
with methyl-alcoholic potassium hydroxide, was converted into a compound, probably 6 : 7-*dimethoxy*-1-*veratryl*-3-*methylnaphthalene* (XI) : a confirmatory synthesis is in progress. The conversion of (X) into (XI) involves elimination of hydrogen chloride and an isomeric change of the eugenol–*iso*eugenol type, which is doubtless facilitated by the aromatic condition of (XI). Attempts to obtain crystalline products by the action of formalin and alkalis on (IX) have been unsuccessful; reaction occurs, but treatment of the amorphous product with acetic and hydrochloric acids has not yielded recognisable products.



(XII.)

$Ph\cdot\overset{CN}{C}H\cdot CO\cdot CH_2\cdot O\cdot CH_2Ph$

(XIII.)



(XIV.)

A method for the synthesis of aryltetronic acids has been found during experiments aiming at the preparation of derivatives of γ-hydroxy-β-keto-α-phenylpropane, by using reactions analogous to those employed by Pfeiffer and Willems (*Ber.*, 1929, **62**, 1242) in the preparation of β-keto-γ-phenoxy-α-phenylpropane (XII; R = H). The conditions necessary for the removal of the phenoxy-group rendered this compound unsuitable for our purpose, and attempts to utilise the *p*-nitrophenoxy-derivative (XII; R = NO_2) were abandoned because the yield of the condensation product of phenylacetonitrile and methyl *p*-nitrophenoxyacetate was small. Protection with the benzyloxy-group was therefore examined. Good yields of β-*keto*-α-*cyano*-γ-*benzyloxy*-α-*phenylpropane* (XIII) were obtained from phenylacetonitrile and methyl benzyloxyacetate, but attempts to hydrolyse the nitrile resulted in elimination of the benzyl group with the formation of phenyltetronic acid (XIV). The reaction appears to be of wide application and *veratryl*- and *piperonyl-tetronic acids* have been prepared. Phenyltetronic acid (XIV) may be converted into phenylacetylcarbinol, or a tautomer (see Danilow and Danilowa, *Ber.*, 1930, **63**, 2765), by heating with water at 200°, but the yield is poor and so far similar conversions have not been realised with the veratryl and piperonyl analogues.

Experimental.

*Dehydroanhydro*iso*lariciresinol Dimethyl Ether* (IV).—Anhydro*iso*lariciresinol dimethyl ether (0·2 g.) and lead tetra-acetate (0·5 g.) were heated at 70—80° for 45 minutes. After dilution with water, the product was extracted with chloroform and washed successively with water and sodium hydroxide solution, and the solvent removed. The residue was refluxed with 5% alcoholic potassium hydroxide (5 c.c.) for 1 hour, the alcohol removed, and water added. The *product*, isolated with chloroform, crystallised from chloroform–methyl alcohol in stout rhombic prisms (0·07 g.), m. p. 201—202° (Found: C, 71·9; H, 6·4. $C_{22}H_{22}O_5$ requires C, 72·1; H, 6·1%). The alcoholic potassium hydroxide treatment was necessary to remove traces of lactonic or acidic products, which were recovered by acidification of the alkaline liquors but have not been investigated.

Triphenylmethyl Ether of Lariciresinol Dimethyl Ether.—Lariciresinol dimethyl ether (2 g.) and triphenylmethyl chloride (1·6 g.) were heated in pyridine (5 c.c.) at 70° for 4 hours. After addition of water, the product was isolated with ether; it crystallised from methyl alcohol in colourless rectangular prisms (2·5 g.), m. p. 134—135° (Found: C, 77·9; H, 6·6. $C_{41}H_{42}O_6$ requires C, 78·1; H, 6·7%). Under similar conditions *iso*lariciresinol dimethyl ether gave a semi-solid unrecognisable product. The *triphenylmethyl ether*, m. p. 134° (0·5 g.), was boiled for 15 minutes with 80% formic acid and cooled, and triphenylcarbinol, m. p. 162°, collected. The filtrate was diluted with water and extracted with ether, and the extract washed with sodium bicarbonate solution, dried, and concentrated; the *diformyl* derivative of *iso*lariciresinol dimethyl ether separated in slender needles, m. p. 102—103° (Found: C, 64·5; H, 6·3; CHO, by hydrolysis and back titration, 13·1. $C_{24}H_{28}O_8$ requires C, 64·8; H, 6·3; 2CHO, 13·0%). Hydrolysis of this diformyl derivative with sodium hydroxide gave *iso*lariciresinol dimethyl ether, m. p. 168°, which could be reconverted into the diformyl derivative by heating with formic acid as described above.

Ethyl αβ-Diveratroylpropionate.—ω-Bromoacetoveratrone (5·3 g.) was added to ethyl sodioveratroylacetate [prepared from the ester (5 g.), m. p. 37—38° (compare Appel, Baker, Hagenbach, and Robinson, this vol., p. 742), and sodium ethoxide (0·45 g.)] in dry ether (50

c.c.). After 24 hours, water was added, the ethereal layer separated, and the solvent removed. The residue crystallised from methyl alcohol in small rectangular prisms (5·7 g.), m. p. 110—111° (Found: C, 64·3; H, 6·0. $C_{23}H_{26}O_8$ requires C, 64·2; H, 6·1%).

Lactone of γ-Hydroxy-α-veratroyl-γ-veratryl-Δ^{β}-butenoic Acid.—Ethyl αβ-diveratroylpropionate (0·2 g.) and 10% methyl-alcoholic potassium hydroxide (10 c.c.) were boiled for ½ hour. The yellow *potassium* salt was collected, washed with methyl alcohol, dissolved in boiling water, and acidified. The precipitate crystallised from alcohol–chloroform in yellow prisms, m. p. 155—156° (Found: C, 65·4; H, 5·3. $C_{21}H_{20}O_7$ requires C, 65·6; H, 5·2%).

αβ-Diveratroylethane.—Ethyl αβ-diveratroylpropionate (0·2 g.) was dissolved in methyl alcohol (0·2 c.c.) and water (0·5 c.c.); N/10-sodium hydroxide (1 c.c.) was added drop by drop to the boiling solution, which turned yellow and deposited colourless needles. After 5 minutes, the crystals were collected and recrystallised from chloroform–alcohol, forming needles (0·15 g.), m. p. 180—181° (Found: C, 67·0; H, 6·2. $C_{21}H_{22}O_6$ requires C, 67·0; H, 6·2%).

2 : 5-*Diveratrylfuran*.—This was prepared in 90% yield by boiling αβ-diveratroylethane with methyl-alcoholic hydrogen chloride (10 parts) for ½ hour; it separated from chloroform–methyl alcohol in slender prisms, m. p. 154—155° (Found: C, 70·8; H, 6·0. $C_{20}H_{20}O_5$ requires C, 70·6; H, 5·9%). The insolubility of this *compound* in sodium hydroxide and the negative ferric test exclude the isomeric 6 : 7-dimethoxy-4-veratryl-1-naphthol structure.

Ethyl Veratroylpyruvate.—Ethyl oxalate (1·6 g.) was added with ice cooling to a mixture of acetoveratrone (2 g.) and potassium ethoxide (from 0·45 g. of potassium) in ether (25 c.c.). After 24 hours, water was added, the aqueous layer acidified, and the precipitate crystallised from methyl alcohol; yellow prisms (1·8 g.), m. p. 104—105° (Found: C, 59·9; H, 5·8. $C_{14}H_{16}O_6$ requires C, 60·0; H, 5·7%), were obtained which gave a violet ferric test. Hydrolysis with the calculated quantity of warm 5% potassium hydroxide solution yielded the *acid*, which separated from methyl alcohol in slender prisms, m. p. 192—193° (decomp.) (Found: C, 57·0; H, 4·6. $C_{12}H_{12}O_6$ requires C, 57·1; H, 4·8%).

Action of Formaldehyde on α-Veratroyl-β-(3′ : 4′-dimethoxybenzyl)butyrolactone (VIII).—The lactone (VIII) (2·0 g.) was dissolved in 2% sodium hydroxide solution (40 c.c.), and 20% formalin (0·8 g.) added. After 3 days, the solution was acidified and extracted with chloroform; the extract yielded veratric acid (0·75 g.), m. p. 180°. The aqueous liquors gave only an oil.

δ-Keto-β-hydroxymethyl-αδ-diveratroylpropane (IX).—The lactone (VIII) (0·5 g.) was boiled with 2% sodium hydroxide solution (20 c.c.) for 2 hours. The oil which gradually separated, and solidified on cooling, was collected; it crystallised from methyl alcohol–ether in slender needles, m. p. 98—99° (Found: C, 67·5; H, 6·8. $C_{21}H_{26}O_6$ requires C, 67·3; H, 6·9%). The *bismethylenedioxy*-analogue of (IX), prepared similarly, crystallised from methyl alcohol in needles, m. p. 103—104° (Found: C, 66·6; H, 5·3. $C_{19}H_{18}O_6$ requires C, 66·7; H, 5·3%), and gave an *oxime*, which separated from methyl alcohol in colourless needles, m. p. 139—140° (Found: C, 64·1; H, 5·5. $C_{19}H_{19}O_6N$ requires C, 63·9; H, 5·4%). These compounds were first prepared in collaboration with Dr. T. Richardson.

6 : 7-*Dimethoxy-1-veratryl-3-chloromethyl-3 : 4-dihydronaphthalene* (X).—Attempts to cyclise the ketone (IX) with methyl-alcoholic hydrogen chloride gave unrecognisable products. The ketone (IX) (1 g.) was dissolved in acetic acid (3 c.c.), and concentrated hydrochloric acid (6 c.c.) added. After 24 hours, the crimson solution was diluted with water and extracted with chloroform. The extract was washed successively with water and sodium bicarbonate solution, the solvent removed, and the residue crystallised from methyl alcohol; colourless rectangular prisms, m. p. 108—109° (Found: C, 67·5; H, 6·1. $C_{21}H_{23}O_4Cl$ requires C, 67·3; H, 6·3%), were obtained.

6 : 7-*Dimethoxy-1-veratryl-3-methylnaphthalene* (XI).—The chloro-compound (X) (0·1 g.) was refluxed with 5% methyl-alcoholic potassium hydroxide (10 c.c.) for 1 hour. The alcohol was removed, and water added; the product, isolated with ether, crystallised from methyl alcohol in well-formed prisms, m. p. 140° (Found: C, 74·4; H, 6·5. $C_{21}H_{22}O_4$ requires C, 74·6; H, 6·6%). The *compound* (XI) can also be purified by sublimation at 0·1 mm. (bath 200—220°) or by crystallisation from light petroleum (b. p. 60—80°).

β-Keto-α-cyano-γ-p-nitrophenoxy-α-phenylpropane (XII; R = NO_2).—*A solution of ethyl* *p*-nitrophenoxyacetate (2 g.) (Minton and Stephen, J., 1922, **121**, 1591) and phenylacetonitrile (1·2 g.) in benzene (5 c.c.) was added to a suspension of potassium ethoxide (from potassium, 0·36 g.) in benzene (20 c.c.). After boiling for 3 hours, the mixture was diluted with water, ·e alkaline layer acidified, and the product extracted with ether. Removal of the solvent crystallisation of the residue from methyl alcohol gave cream-coloured needles (0·2 g.), 6 : 7-·56—157° (Found: N, 9·7. $C_{16}H_{12}O_4N_2$ requires N, 9·5%).

β-Keto-α-cyano-γ-benzyloxy-α-phenylpropane (XIII).—Benzyloxyacetic acid (Fischer and Gohlke, *Helv. Chim. Acta*, 1933, **16**, 1130) was esterified with 10% methyl-alcoholic sulphuric acid (Rothstein, *Bull. Soc. chim.*, 1932, **51**, 691). The methyl ester (3 g.), b. p. 160—162°/2 mm., and phenylacetonitrile (1·6 g.) were heated for 2 hours on the water-bath with a solution of sodium ethoxide (from sodium, 0·36 g.) in absolute alcohol (10 c.c.). Most of the alcohol was evaporated, water added, and neutral substances removed in ether. The alkaline liquors were acidified; the *product*, isolated with ether, crystallised from ether–light petroleum (b. p. 60—80°) in colourless plates (3 g.), m. p. 72—73° (Found: C, 77·2; H, 5·4. $C_{17}H_{15}O_2N$ requires C, 77·0; H, 5·3%), which gave a deep blue ferric test.

β-Keto-α-cyano-γ-benzyloxy-α-veratrylpropane, prepared similarly from veratrylacetonitrile (2 g.), separated from ether–light petroleum (b. p. 60—80°) in colourless prisms (2·5 g.), m. p. 78—79° (Found: C, 70·2; H, 6·1. $C_{19}H_{19}O_4N$ requires C, 70·2; H, 5·9%), which gave with ferric chloride a blue colour which gradually became green.

β-Keto-α-cyano-γ-benzyloxy-α-piperonylpropane, prepared from piperonylacetonitrile (2 g.), separated from ether–light petroleum (b. p. 60—80°) in colourless felted needles (2·3 g.), m. p. 72—73° (Found: C, 70·1; H, 5·0. $C_{18}H_{15}O_4N$ requires C, 69·9; H, 4·8%), which gave with ferric chloride a blue colour, which rapidly became green and finally colourless.

Phenyltetronic Acid (XIV).—The cyano-ketone (XIII) (5 g.) was dissolved in methyl alcohol (20 c.c.), and dry hydrogen chloride passed through the boiling solution for 4 hours. The alcohol and benzyl chloride were removed under diminished pressure; the residue was taken up in sodium bicarbonate solution, filtered, and recovered. The product crystallised from methyl alcohol in colourless stout prisms (1·6 g.), m. p. 252—253° (Dimroth and Elble, *Ber.*, 1906, **39**, 3929, give m. p. 254°) (Found: C, 68·1; H, 4·7. Calc. for $C_{10}H_8O_3$: C, 68·2; H, 4·6%), which gave a dark green ferric test. This tetronic acid (0·5 g.) was heated with water (5 c.c.) in a sealed tube at 200° for 8 hours. The product was extracted with ether, the extract washed with dilute sodium hydroxide solution, and the solvent removed; the residue crystallised from light petroleum (b. p. 40—60°) in colourless plates (0·05 g.), m. p. 51—52° (Danilow and Danilowa, *loc. cit.*) (Found: C, 72·3; H, 7·0. Calc. for $C_9H_{10}O_2$: C, 72·0; H, 6·7%), which reduced Fehling's solution and ammoniacal silver nitrate solution.

Veratryltetronic acid, prepared similarly, crystallised from methyl alcohol in cream-coloured cubes, m. p. 211—213° (Found: C, 61·4; H, 5·3. $C_{12}H_{12}O_5$ requires C, 61·0; H, 5·1%), which gave a green ferric test.

Piperonyltetronic acid crystallised from glacial acetic acid in colourless prisms, m. p. 268° (decomp.) (Found: C, 59·7; H, 3·9. $C_{11}H_8O_5$ requires C, 60·0; H, 3·6%), which gave a green ferric test.

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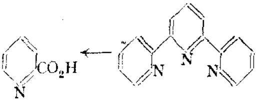
347. *Researches on Residual Affinity and Co-ordination. Part XXXVII. Complex Metallic Salts containing 2 : 6-Di-2′-pyridylpyridine (2 : 2′ : 2″-Tripyridyl).*

By SIR GILBERT MORGAN and FRANCIS H. BURSTALL.

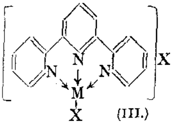
A number of reactions of the triamine 2 : 6-di-2′-pyridylpyridine (2 : 2′ : 2″-tripyridyl) are described. Oxidation of the base with alkaline permanganate yields only pyridine-2-carboxylic acid, thus indicating that it is the central one of three pyridine rings which is preferentially attacked. The triamine acts as a tridentate group and furnishes many stable and characteristic co-ordination compounds. This group of salts is divided into two series which contain severally one and two molecular proportions of base to each atom of metal. The first series is of monotridentate types [M tripy X] and [M tripy X]X, where M = copper, univalent and bivalent silver, zinc, cadmium, mercury, palladium and platinum. Tervalent iridium chloride yields [$IrCl_3$ tripy]. The second series is of bistridentate type represented by the general formulæ [M 2tripy]X_2 and [M 2tripy]X_3,nH_2O, where M = bivalent iron, bi- and ter-valent cobalt, nickel, bivalent ruthenium, bivalent osmium and tervalent chromium.

IN the course of a comprehensive study of the dehydrogenation of pyridine by anhydrous metallic chlorides (J., 1932, 20; *J. Indian Chem. Soc.*, 1933, Ray Commemoration Vol.,

p. 1) we recorded the isolation of a new triamine, 2 : 6-di-2′-pyridylpyridine (2 : 2′ : 2″-tripyridyl) (*I*), as one of some twenty products identified in these condensations. This base was characterised by the formation of a deep purple coloration with ferrous salts and a noteworthy series of complex platinum derivatives (J., 1934, 1498). In the first communication dealing with this base (J., 1932, 20) two triamines designated as 2 : 2′ : 2″-tripyridyl and 2 : 2′ : *x*″-tripyridyl were described, but it has now been found that these products are dimorphous forms of the same substance. Although these two crystalline species differ slightly in melting point, 88—89° and 85—86°, they both give the same compounds and are readily converted one into the other. In order to obtain formal proof of its constitution, 2 : 6-di-2′-pyridylpyridine was oxidised with alkaline potassium permanganate solution. The only acid of the pyridine series isolated from the oxidised



(II.) (I.)



(III.)

base was pyridine-2-carboxylic acid (picolinic acid) (II), which was obtained in such yield as to indicate that it is the centre ring of the triamine which is preferentially attacked. There is no evidence of the formation of either pyridine-2 : 6-dicarboxylic acid or of 2 : 2′-dipyridyl-6-carboxylic acid.

In combination with metallic salts, notably those of the transition elements, 2 : 6-di-2′-pyridylpyridine yields two series of derivatives containing severally one and two molecules of base to each atom of metal. The former type is represented by the salts of copper, silver, zinc, cadmium, mercury, palladium, iridium and platinum, whereas the latter series comprises the complex derivatives of iron, cobalt, nickel, ruthenium, osmium and chromium.

The bivalent compounds of copper, silver, palladium and platinum are regarded as possessing a planar configuration (III), which is in keeping with the known structure of other 4-co-ordinated derivatives of these metals. The arrangement of addenda round the univalent silver ion and the bivalent zinc, cadmium and mercury atoms is more speculative; a planar configuration is not excluded, although a tetrahedral arrangement appears to be inadmissible if these salts are to be regarded as monomeric. Moreover, the triamine should possess a planar distribution of its three pyridine rings in order to satisfy the mesomerism possible in such a molecule. If this effect is manifested, this tridentate base cannot span the three sides of a tetrahedron without some distortion of its molecule and accordingly a planar arrangement of four covalent complex salts is favoured.

The remaining compounds described in this paper are those in which the metal manifests a co-ordination number of 6. Accordingly, these derivatives will have the characteristic octahedral arrangement of their addenda round a central metallic atom.

Monotridentate Types, [MX tripy] *and* [MX tripy]X.

Copper Salt.—In aqueous solution cupric chloride and 2 : 6-di-2′-pyridylpyridine (2 : 2′ : 2″-tripyridyl) yield a bright green, sparingly soluble *chloride,* [CuCl tripy]Cl,$2H_2O$, even in presence of excess of the base. Although the presence of a salt containing a larger proportion of the triamine is indicated by an increased solubility of the foregoing compound in an aqueous alcoholic solution of the base, a further combination could not be isolated.

Univalent Silver Salts.—Silver nitrate and the triamine yield a compound of the empirical formula [tripy $AgNO_3$] and as univalent silver salts manifesting a co-ordination number of 4 usually possess a tetrahedral structure which, for reasons already given, is regarded as inadmissible, it is doubtful whether a simple formula will suffice to interpret the constitution of this compound. It is possible that only one or perhaps two of the three associating foci of the organic base are co-ordinated to one atom of the metal. The corresponding *perchlorate,* [tripy $AgClO_4$], is of similar type.

Bivalent Silver Salts.—In the presence of dilute nitric acid the foregoing nitrate

[tripy $AgNO_3$] is readily oxidised at the anode of an electrolytic cell with the formation of 2 : 2′ : 2″-*tripyridylargentic nitrate*, [$AgNO_3$ tripy]NO_3. This dark brown derivative containing bivalent silver is soluble in water and from the solution the corresponding *chlorate*, [$AgClO_3$ tripy]ClO_3, *perchlorate*, [$AgClO_4$ tripy]ClO_4, and *dithionate*, [AgS_2O_6 tripy], can be obtained by double decomposition. An alternative mode of preparation follows from the oxidation of the univalent silver salt [tripy $AgNO_3$] with aqueous potassium persulphate, brown insoluble 2 : 2′ : 2″-*tripyridylargentic persulphate*, [AgS_2O_8 tripy], being formed :

$$2[\text{tripy } Ag^{I}NO_3] + 3K_2S_2O_8 = 2[Ag^{II}S_2O_8 \text{ tripy}] + 2KNO_3 + 2K_2SO_4.$$

This persulphate yields the corresponding bivalent nitrate with nitric acid. Following the results obtained by Cox, Wardlaw, and Webster (J., 1936, 775) with argentic picolinate $(C_6H_4O_2N)_2Ag$, the foregoing 2 : 2′ : 2″-tripyridylargentic salts are regarded as having a planar configuration. This arrangement of addenda may with equal justice be extended to complex silver salts containing pyridine [Ag 4py]X_2 (Barbieri, *Gazzetta*, 1912, **42**, 7 ; *Ber.*, 1927, **60**, 2424), α-phenanthroline [Ag 2phenan]X_2 (Hieber and Mühlbauer, *Ber.*, 1928, **61**, 2149), and 2 : 2′-dipyridyl [Ag 2dipy]X_2 (Morgan and Burstall, J., 1930, 2594 ; Barbieri, *Atti R. Accad. Lincei*, 1932, **16**, 44).

Moreover, there is no indication of the formation of a bivalent silver derivative containing more than one molecule of the triamine in combination with each atom of silver.

Zinc, Cadmium and Mercuric Salts.—Salts of these three elements yield characteristic compounds with the triamine. Zinc chloride and cadmium chloride in aqueous solution furnish the sparingly soluble *chlorides* [ZnCl tripy]Cl and [CdCl tripy]Cl, whereas mercuric nitrate yields [$HgNO_3$ tripy]NO_3.

4-Co-ordinated derivatives in this group of elements are normally tetrahedral in structure. Accordingly the constitution of the zinc, cadmium and mercury compounds will probably be more complicated than is indicated by the foregoing formulæ. This possibility has already been mentioned in the case of univalent silver.

It is noteworthy that neither beryllium nor magnesium chloride gives compounds under similar conditions.

Palladium, Platinum and Iridium Salts.—In aqueous medium, potassium palladochloride or palladium dichloride and 2 : 2′ : 2″-tripyridyl unite to form the stable complex chloride [PdCl tripy]Cl,$3H_2O$. This soluble yellow derivative is very similar to the corresponding orange-red platinous salt [PtCl tripy]Cl,$3H_2O$ which has already been described (J., 1934, 1498). It is concluded that both these chlorides have a planar configuration, in keeping with the known structure of many 4-covalent palladium and platinum salts. Potassium iridochloride, $K_3[IrCl_6]$, and 2 : 2′ : 2″-tripyridyl in aqueous solution afford the sparingly soluble chloride [tripy $IrCl_3$] corresponding with the platinic derivative [$PtCl_3$ tripy]Cl,$2H_2O$. Both these salts possess 6-co-ordinated structures characterised by an octahedral distribution of addenda round the metallic atom.

Bistridentate Types, [M 2tripy]X_2 *and* [M 2tripy]X_3,nH_2O.

An octahedral structure is also advanced for a group of complex metallic salts containing two molecules of 2 : 6-di-2′-pyridylpyridine. The compounds are all of the general type [M 2tripy]$X_{2 \text{ or } 3}$,yH_2O, where M = iron, ruthenium osmium, cobalt, nickel, or chromium and X is a univalent acid radical. The arrangement of two tridentate groups round the six vertices of an octahedron leads to the three stereoisomeric compounds represented by the structures (IV), (V) and (VI).

cannot be excluded, whereas (V) should exist in optically active forms, but there is no evidence of any resolution among nickel and ruthenium derivatives, which are among the most stable salts of this series.

Iron, Ruthenium and Osmium Salts.—2 : 2′ : 2″-Tripyridyl was first discovered from the intense purple colour which it gave with ferrous salts. On addition of a soluble bromide to the concentrated red aqueous solution of ferrous sulphate and the base, *bis*-2 : 2′ : 2″-*tripyridylferrous bromide tetrahydrate*, [Fe 2tripy]Br_2,$4H_2O$, separates and this tetrahydrated bromide yields a *monohydrate* when left over sulphuric acid. The *iodide*, [Fe 2tripy]I_2,H_2O, is obtained from the bromide by double decomposition. The intense purple colour of these salts provides a specific and sensitive test for ferrous ions up to dilutions of about 1 in 2 million parts of water. This fact has been utilised in the determination of iron in the sea and marine plankton (Cooper, *Proc. Roy. Soc.*, 1935, *B*, **118**, 419). The ruthenium salts are represented by the red chloride, [Ru 2tripy]Cl_2,$4H_2O$, which arises from the condensation of 2 : 2′ : 2″-tripyridyl, ruthenium trichloride and metallic ruthenium at 250—260°. This bivalent ruthenium salt possesses the noteworthy stability associated with the corresponding 2 : 2′-dipyridyl analogue (J., 1936, 173), although precipitation with ammonium *d*-tartrate, followed by regeneration of the chloride, gives only optically inactive preparations. The osmium series of salts results from the reaction between the triamine, potassium osmichloride and metallic osmium at 250—260°. The green chloride, [Os 2tripy]Cl_2,$4H_2O$, furnishes an almost black iodide, [Os 2tripy]I_2,H_2O. The bivalent ion [Os 2tripy]$^{\cdot\cdot}$ is remarkably stable to both acids and alkalis.

Cobalt, Nickel and Chromium Salts.—Cobaltous salts and 2 : 2′ : 2″-tripyridyl furnish stable, deep brown solutions, from which soluble bromides precipitate almost black crystals of the *hydrated bromide*, [Co 2tripy]Br_2,$3\frac{1}{2}H_2O$; this yields a *monohydrate* over sulphuric acid. The *iodide* also is monohydrated. Chlorine oxidises a solution of cobalt chloride and the triamine in water, forming the stable, pale yellow cobaltic *chloride*, [Co 2tripy]Cl_3,$7H_2O$.

Nickel salts furnish light brown salts exemplified by the *bromide*, [Ni 2tripy]Br_2,1 and $3\frac{1}{2}H_2O$, *iodide* ($1H_2O$), and *tartrate* ($4H_2O$). These salts are quite comparable with the corresponding 2 : 2′-dipyridylnickel salts in stability towards aqueous acids and alkalis, but there is no evidence of optical resolution of the ion [Ni 2tripy]$^{\cdot\cdot}$ after fractional deposition of the foregoing tartrate.

The complex chromium chloride [Cr 2tripy]Cl_3,$2H_2O$ arising from combination of its generators in hot aqueous medium is a yellow salt very similar to the analogous cobaltic derivative.

EXPERIMENTAL.

2 : 6-*Di*-2′-*pyridylpyridine* (2 : 2′ : 2″-*Tripyridyl*) (I).—This base, which arose from the reaction between pyridine and ferric chloride or pyridine ferrichloride, was purified according to the method already described (J., 1932, 28). It was usually obtained in hard white tabular crystals, m. p. 88—89°, but rapid crystallisation from a concentrated ethereal solution yielded fine needles, m. p. 85—86°. A mixture of the two forms gave no perceptible lowering in m. p. The compound formerly described as 2 : 2′ : *x*″-tripyridyl (*ibid.*, p. 29) was shown to be identical with this base after repeated crystallisation from ether or petroleum (b. p. 40—60°).

2 : 2′ : 2″-*Tripyridyl trihydrochloride tetrahydrate* separated in colourless crystals on evaporation of the triamine with excess of hydrochloric acid. It was extremely soluble in water and decomposed without melting at 280—285° (Found: Cl, 25·3. $C_{15}H_{22}O_4N_3Cl_3$ requires Cl, 25·8%).

Oxidation of 2 : 2′ : 2″-*Tripyridyl.*—The base (7 g.), suspended in water (200 c.c.) and 2N-caustic potash (50 c.c.), was treated gradually with potassium permanganate (47 g.) in water (2 l.), and the mixture refluxed until the pink colour of the permanganate had disappeared. The hot mixture was filtered, and the residue of hydrated manganese oxide washed with alcohol to remove unchanged base. The filtrate and alcoholic washings were mixed and evaporated to about 700 c.c., cooled, and the unchanged base (2 g.) separated. The aqueous liquor after acidification with acetic acid was evaporated further and treated with excess of aqueous copper acetate. After 24 hours the precipitate of copper picolinate was suspended in water and treated with hydrogen sulphide. Evaporation of the filtrate from copper sulphide yielded picolinic acid, m. p. 135° (2·0 g.). A further small quantity was obtained from the residue left after separation

of the copper picolinate by treatment with hydrogen sulphide, followed by evaporation with excess of hydrochloric acid and extraction of the residue with alcohol; this alcoholic extract then gave a little more copper picolinate (0·5 g.) with copper acetate.

2 : 2′ : 2″-*Tripyridylcupric Chloride Dihydrate*.—Cupric chloride (1·7 g.) and 2 : 2′ : 2″-tripyridyl (2·3 g.) were heated in water (500 c.c.) until a homogeneous blue solution was obtained. On cooling, bright green crystals of the complex *chloride* were deposited. A further quantity was obtained by evaporating the filtrate. This salt was air-dried (Found : Cu, 15·6; Cl, 17·3; N, 10·4. $C_{15}H_{15}O_2N_3Cl_2Cu$ requires Cu, 15·8; Cl, 17·6; N, 10·5%). The same salt was produced when twice the quantity of triamine (4·6 g.) was heated with cupric chloride (1·7 g.) in water. It was sparingly soluble in water and alcohol.

2 : 2′ : 2″-*Tripyridylargentous Nitrate*.—Silver nitrate (1·7 g.) and 2 : 2′ : 2″-tripyridyl (2·3 g.) were heated in aqueous alcohol until a clear solution resulted; evaporation and cooling then gave white needles of the complex *nitrate*, which was recrystallised from water or aqueous alcohol and dried over sulphuric acid (Found : Ag, 26·5; N, 13·6. $C_{15}H_{11}O_3N_4Ag$ requires Ag, 26·8; N, 13·9%). It was moderately easily soluble in water or alcohol.

2 : 2′ : 2″-*Tripyridylargentous perchlorate* was precipitated as a sparingly soluble, white, crystalline powder when aqueous sodium perchlorate was added to a solution of the foregoing nitrate. After being washed with cold water, it was recrystallised from boiling water (Found : Ag, 24·3; N, 9·7. $C_{15}H_{11}O_4N_3ClAg$ requires Ag, 24·5; N, 9·5%).

2 : 2′ : 2″-*Tripyridylargentic Nitrate*.—75 C.c. of a solution containing 2 : 2′ : 2″-tripyridylargentous nitrate (3·0 g.) and concentrated nitric acid (8 g.) were placed in a porous pot which constituted the anode compartment of an electrolytic cell. The anode consisted of platinum foil; the cathode was a length of platinum wire dipping into a solution of N/5-nitric acid. A current of 8 volts and 2—3 amps. was passed through this cell for 3 hours. The contents of the anode compartment, which were cooled, if necessary, and stirred by a stream of air, speedily became deep brown and brown crystals separated on the bottom and sides of the porous vessel. At the end of the electrolysis the anodic products were cooled to 0° after the addition of concentrated aqueous ammonium nitrate. The deep brown, almost black crystals were then separated and recrystallised from water (40°) by cooling at 0° (Found : C, 38·4; H, 2·2; N, 15·0; Ag, 22·9, 23·3; active O, 1·6. $C_{15}H_{11}O_6N_5Ag$ requires C, 38·7; H, 2·4; N, 15·1; Ag, 23·2; active O, 1·7%). This complex *nitrate* dissolved readily in water to a deep brown solution, which soon decomposed; the solid product, however, was stable under normal conditions. Aqueous solutions were at once decomposed by alcohol, alkalis, and halogen acids. The reaction with potassium iodide formed the basis for estimating bivalent silver in the molecule :

$$2[AgNO_3\ \text{tripy}]NO_3 + 4KI = 2AgI + 2\text{tripy} + 4KNO_3 + I_2$$

Each molecule of the bivalent nitrate contains the equivalent of half an atomic proportion of active oxygen. The iodine liberated was titrated with N/10-sodium thiosulphate. This complex nitrate was the starting material for the preparation of the following three compounds containing bivalent silver.

2 : 2′ : 2″-*Tripyridylargentic chlorate*, obtained in almost black, lustrous crystals on addition of excess of a concentrated solution of sodium chlorate to a saturated solution of the nitrate, was purified by dissolution in water and addition of aqueous sodium chlorate (Found : Ag, 20·8; N, 8·4; active O, 1·6. $C_{15}H_{11}O_6N_3Cl_2Ag$ requires Ag, 21·2; N, 8·3; active O, 1·6%).

2 : 2′ : 2″-*Tripyridylargentic perchlorate* was precipitated as a russet-brown crystalline salt when aqueous sodium perchlorate was added to a solution of the corresponding nitrate. It was also formed by the anodic oxidation of a suspension of the univalent silver salt, 2 : 2′ : 2″-tripyridylargentous perchlorate, in aqueous perchloric acid in a divided cell. It was sparingly soluble in water (Found : Ag, 19·9; N, 8·0; active O, 1·45. $C_{15}H_{11}O_8N_3Cl_2Ag$ requires Ag, 20·0; N, 7·8; active O, 1·5%).

2 : 2′ : 2″-*Tripyridylargentic dithionate* separated in dark brown crystals when concentrated solutions of sodium dithionate and 2 : 2′ : 2″-tripyridylargentic nitrate were mixed; it was washed with ice-cold water and dried (Found: Ag, 21·4; N, 8·5; active O, 1·56. $C_{15}H_{11}O_6N_3S_2Ag$ requires Ag, 21·5; N, 8·4; active O, 1·6%).

2 : 2′ : 2″-*Tripyridylargentic Persulphate*.—The white crystals of the univalent silver salt [tripy $AgNO_3$], when added in aqueous suspension to an aqueous solution containing an excess of potassium persulphate, slowly changed to the characteristic brown crystals of the bivalent *persulphate*. After 12 hours this was separated, washed with cold water, and dried (Found : Ag, 20·1; N, 8·1; active O, 2·9. $C_{15}H_{11}O_8N_3S_2Ag$ requires Ag, 20·3; N, 7·9; active O, 3·0%).

It gave 2 : 2′ : 2″-tripyridylargentic nitrate when stirred with cold nitric acid (50% nitric acid, *d* 1·4, and 50% water).

2 : 2′ : 2″-*Tripyridylzinc Chloride*.—Zinc chloride (1·3 g.) and 2 : 2′ : 2″-tripyridyl (2·3 g.) were mixed in water (50 c.c.) and heated until the base gave place to the complex *chloride*. The product crystallised from much hot water in pale yellow needles, which were air-dried (Found : Zn, 17·9; Cl, 19·2. $C_{15}H_{11}N_3Cl_2Zn$ requires Zn, 17·7; Cl, 19·2%). This complex salt and 2 : 2′ : 2″-tripyridyl were mutually soluble in water, but the resulting compound was too unstable to be isolated. The excess of base could be recovered by evaporation and extraction with acetone.

2 : 2′ : 2″-*Tripyridylcadmous Chloride*.—Cadmium chloride (1·8 g.) and 2 : 2′ : 2″-tripyridyl (2·3 g.) were boiled in an aqueous medium (100 c.c.). The microcrystalline *chloride* was separated and recrystallised from much water, forming anhydrous, small, pale yellow crystals even less soluble in water than the foregoing zinc derivative (Found : Cd, 27·2; Cl, 16·7. $C_{15}H_{11}N_3Cl_2Cd$ requires Cd, 27·0; Cl, 17·0%).

2 : 2′ : 2″-*Tripyridylmercuric nitrate* was formed when equimolecular quantities of its generators were mixed in an aqueous medium. This pale yellow, sparingly soluble nitrate was crystallised from hot water and air-dried (Found : Hg, 36·3. $C_{15}H_{11}O_6N_5Hg$ requires Hg, 36·0%).

2 : 2′ : 2″-*Tripyridylpalladous Chloride Trihydrate*.—Palladium dichloride (1·7 g.) in water (100 c.c.) was boiled with 2 : 2′ : 2″-tripyridyl (2·3 g.). The deep yellow solution was cooled, filtered, and acidified with hydrochloric acid; the complex *chloride* then separated in primrose-yellow leaflets. After crystallisation from water acidified with hydrochloric acid, the salt was air-dried (Found : Pd, 23·3; N, 9·0; H_2O, 11·1. $C_{15}H_{11}N_3Cl_2Pd,3H_2O$ requires Pd, 23·0; N, 9·0; H_2O, 11·6%). It was also formed by heating equimolecular quantities of potassium palladochloride and 2 : 2′ : 2″-tripyridyl in an aqueous medium.

2 : 2′ : 2″-*Tripyridyliridium Trichloride*.—Molecular quantities of sodium iridochloride, $Na_3[IrCl_6]$, and 2 : 2′ : 2″-tripyridyl were heated in aqueous solution; the green tint of the iridochloride speedily changed to orange-yellow and the sparingly soluble, orange-yellow complex *salt* separated. It was crystallised from aqueous alcohol containing a little of the triamine and washed with water and alcohol (Found : Ir, 36·1; N, 8·0; Cl, 19·9. $C_{15}H_{11}N_3Cl_3Ir$ requires Ir, 36·3; N, 7·9; Cl, 20·0%).

Bis-2 : 2′ : 2″-*tripyridylferrous Bromide Tetrahydrate*.—When ferrous sulphate (2·7 g.) in water (150 c.c.) and 2 : 2′ . 2″-tripyridyl (4·6 g.) were warmed together, the base slowly dissolved with formation of a deep purple solution, which was evaporated to half its volume, filtered, and treated with excess of a concentrated solution of potassium bromide. The separated complex *bromide* was slowly crystallised from a cold solution in water and air-dried (Found : Fe, 7·2; Br, 21·0; H_2O, 9·4. $C_{30}H_{22}N_6Br_2Fe,4H_2O$ requires Fe, 7·4; Br, 21·2; H_2O, 9·55%). Exposure over sulphuric acid gave the *monohydrate* with loss of three molecules of water (Found : Br, 22·75; H_2O, 2·5. $C_{30}H_{22}N_6Br_2Fe,H_2O$ requires Br, 22·9; H_2O, 2·6%). The sesquihydrate ($1\frac{1}{2}H_2O$) recorded in an earlier communication (J., 1932, 22) consisted mainly of this monohydrate together with a small proportion of the tetrahydrate.

Bis-2 : 2′ : 2″-*tripyridylferrous iodide monohydrate* was obtained in deep purple crystals by addition of aqueous potassium iodide to a solution of the foregoing bromide (Found : Fe, 6·9; N, 10·7; I, 31·6; H_2O, 2·5. $C_{30}H_{22}N_6I_2Fe,H_2O$ requires Fe, 7·0; N, 10·6; I, 32·0; H_2O, 2·3%).

Bis-2 : 2′ : 2″-*tripyridylruthenous Chloride Tetrahydrate*.—Ruthenium trichloride (1·0 g.), metallic ruthenium (0·5 g.), and 2 : 2′ : 2″-tripyridyl (10 g.) were heated at 250—260° with stirring. After 3 hours the cooled melt was extracted with benzene to remove the excess of triamine. The residue was treated with water and filtered, and the red solution evaporated to crystallising point. The red crystals were recrystallised from water and air-dried (Found : Ru, 14·6; N, 11·7; Cl, 10·15; H_2O, 10·4. $C_{30}H_{22}N_6Cl_2Ru,4H_2O$ requires Ru, 14·3; N, 11·8; Cl, 10·0; H_2O, 10·2%). This dark red ruthenium *salt* was not decomposed by concentrated hydrochloric acid or concentrated aqueous alkali hydroxide. A 10% solution of the chloride gave a crystalline tartrate when stirred with ammonium *d*-tartrate at 0°. Regeneration of the chloride from the tartrate yielded a preparation which gave no perceptible rotation in a polarimeter.

Bis-2 : 2′ : 2″-*tripyridylosmous Chloride Tetrahydrate*.—Potassium osmichloride, $K_2[OsCl_6]$ (1·0 g.), metallic osmium (0·5 g.), and 2 : 2′ : 2″-tripyridyl were heated at 250—260° with stirring for 3 hours. The product was extracted successively with benzene and water. The aqueous extract after filtration and evaporation yielded green needles of the *chloride*, which were recrystallised from the minimum quantity of water (Found : Os, 23·7; Cl,

9·2. $C_{30}H_{22}N_6Cl_2Os,4H_2O$ requires Os, 23·9; Cl, 8·9%). This osmium salt gave a red solution in water or alcohol and was notably stable towards aqueous halogen acids and alkali hydroxides.

Bis-2 : 2′ : 2″-tripyridylosmous Iodide Hydrate.—The addition of potassium iodide solution to a solution of the foregoing chloride gave almost black crystals of the *iodide* (Found: Os, 20·3. $C_{30}H_{22}N_6I_2Os,H_2O$ requires Os, 20·6%).

Bis-2 : 2′ : 2″-tripyridylcobaltous Bromide Hydrate.—An aqueous solution of cobalt bromide (2·2 g. in 100 c.c. of water) and 2 : 2′ : 2″-tripyridyl (4·6 g.) were boiled together until the base dissolved. The deep brown solution was evaporated and cooled; dark brown crystals of the complex *bromide* then separated (Found: Co, 7·8; H_2O, 8·3. $C_{30}H_{22}N_6Br_2Co,3\frac{1}{2}H_2O$ requires Co, 7·9; H_2O, 8·4%). After desiccation over sulphuric acid the *monohydrate* was formed (Found: Co, 8·2; N, 11·9; Br, 22·4; H_2O, 2·5. $C_{30}H_{22}N_6Br_2Co,H_2O$ requires Co, 8·4; N, 11·9; Br, 22·7; H_2O, 2·6%). This bromide was slowly decomposed by 2N-hydrochloric acid and 2N-aqueous alkali hydroxide.

Bis-2 : 2′ : 2″-tripyridylcobaltous iodide hydrate was obtained by double decomposition of the foregoing bromide with potassium iodide in aqueous solution (Found: N, 10·7; I, 32·0; H_2O, 2·0. $C_{30}H_{22}N_6I_2Co,H_2O$ requires N, 10·6; I, 31·9; H_2O, 2·3%). It was much less soluble than the foregoing bromide.

Bis-2 : 2′ : 2″-tripyridylcobaltic Chloride Heptahydrate.—Cobalt chloride (2·4 g.) and 2 : 2′ : 2″-tripyridyl (4·6 g.) were boiled with water until the base dissolved. Chlorine was passed into the mixture, the deep brown colour becoming lighter, and the solution was evaporated to a syrup at 90° and stirred with alcohol at 0°; the yellow crystals that separated were recrystallised from water by cooling a concentrated solution at 0°. This hygroscopic *salt* was kept over sulphuric acid (Found: Co, 7·7; Cl, 13·8; H_2O, 16·5. $C_{30}H_{22}N_6Cl_3Co,7H_2O$ requires Co, 7·8; Cl, 14·0; H_2O, 16·7%). It was decomposed by alkali hydroxide, but not by 2N-mineral acid.

Bis-2 : 2′ : 2″-tripyridylnickel Bromide Hydrate.—Nickel sulphate (2·8 g.) and 2 : 2′ : 2″-tripyridyl (4·6 g.) were boiled with water (100 c.c.) until the base dissolved. The brown liquid was evaporated, cooled, and treated with an excess of potassium bromide solution. The pale brown, crystalline deposit slowly crystallised from warm water and when air-dried consisted of a complex bromide with $3\frac{1}{2}H_2O$ (Found: H_2O, 8·7. Calc., 8·4%). After keeping over sulphuric acid the *monohydrate* was formed (Found: Ni, 8·2; N, 11·9; Br, 22·5; H_2O, 2·4. $C_{30}H_{22}N_6Br_2Ni,H_2O$ requires Ni, 8·35; N, 12·0; Br, 22·7; H_2O, 2·6%). This complex bromide was decomposed by warm 2N-hydrobromic acid, but was rather more stable towards the same strength of caustic alkali.

Bis-2 : 2′ : 2″-tripyridylnickel iodide hydrate was obtained from the foregoing bromide by double decomposition with aqueous potassium iodide. This sparingly soluble iodide crystallised in light brown needles from hot water (Found: Ni, 7·4; N, 10·7. $C_{30}H_{22}N_6I_2Ni,H_2O$ requires Ni, 7·4; N, 10·6%).

Bis-2 : 2′ : 2″-tripyridylnickel Tartrate Tetrahydrate.—A saturated solution of the complex bromide in water was stirred at 0° with excess of solid ammonium *d*-tartrate; brown leaflets of the complex d-*tartrate* separated slowly. This product and the liquid were decanted from undissolved ammonium tartrate and the separated solid was crystallised from water and dried (Found: Ni, 7·7; H_2O, 9·9. $C_{34}H_{26}O_6N_6Ni,4H_2O$ requires Ni, 7·9; H_2O, 9·7%). Addition of potassium bromide to this tartrate gave the complex bromide, which was optically inactive.

Bis-2 : 2′ : 2″-tripyridylchromic Chloride Dihydrate.—Anhydrous chromic chloride (1·5 g.) and 2 : 2′ : 2″-tripyridyl (4·6 g.) with a trace of zinc dust as catalyst were boiled with water until most of the reagents dissolved. The filtered, deep brown solution was evaporated to a small volume and treated with acetone; a brown oil then separated which gradually yielded small yellowish-brown crystals. This *chloride* was purified by repetition of this precipitation of the aqueous solution with acetone and dried over sulphuric acid (Found: Cr, 7·95; N, 12·55. $C_{30}H_{22}N_6Cl_3Cr,2H_2O$ requires Cr, 7·9; N, 12·7%). A solution of this salt deposited some chromic oxide on boiling.

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348. *The Oxidation of Propane. Part I. The Products of the Slow Oxidation at Atmospheric and at Reduced Pressures.*

By D. M. Newitt and L. S. Thornes.

The oxidation of propane has been studied in the " slow combustion " and the " cool flame " region at atmospheric and at reduced pressures.

The distribution of oxygen in the products has been determined by analysis, and the formation of cool flames has been identified with the presence of a critical concentration of higher aldehydes in the reacting medium. The conditions for the propagation of a succession of cool flames during the reaction of an equimolecular propane–oxygen medium have been investigated.

From a structural point of view propane occupies an important position between the lower and the higher members of the paraffin hydrocarbons, differing from the former in that it has a secondary C—H linkage of the type $R{-}\overset{\text{H}}{\underset{\text{H}}{\text{C}}}{-}R$ and an $H{-}\overset{\text{H}}{\underset{\text{H}}{\text{C}}}{-}\overset{\text{H}}{\underset{\text{H}}{\text{C}}}{-}R$ linkage, and from the latter in that the $:CH_2$ group comes under the influence of the two end methyl groups; and these peculiarities of structure suggest that a study of its oxidation characteristics would be of interest in relation to the mechanism of hydrocarbon combustion generally.

Apart from the work of Pease (*J. Amer. Chem. Soc.*, 1929, **51**, 1839; **1934, 56, 2034**; 1935, **57**, 2296), Prettre (*Bull. Soc. chim.*, **1932, 51**, 1132), and Townend (*Proc. Roy. Soc.*, 1936, *A*, **154**, 95) and their collaborators, however, only scanty data on its oxidation are available. Pease and Munro, from a careful examination of the oxidation products in a flow system, suggested a rather complicated chain mechanism based upon the initial formation of radicals of the type C_3H_7, C_2H_5O, and CH_3O; Prettre, also employing a flow system, located two zones of inflammation at 304° and 670° severally, and Townend and Chamberlain measured the spontaneous ignition temperatures of a number of propane–air mixtures at various pressures up to 14 atm. and recorded their critical transition pressures in a static system.

Experimental.

The flow method employed by Prettre and Pease (*locc. cit.*) is open to some objections when applied to highly exothermic oxidation reactions which may be preceded by long induction periods; for example, when the time of contact of the reacting medium in the heated zone is comparable with the induction period, the rate of reaction as measured by the oxygen consumption is misleading. It is also difficult to avoid local evolution of heat and the consequent formation of temperature gradients in the reaction zone when combustion is proceeding rapidly.

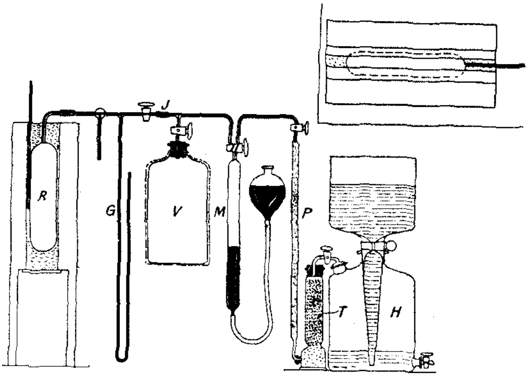
For these and other reasons we have adopted a static method in which the previously mixed hydrocarbon–oxygen medium is rapidly admitted to a reaction vessel maintained at any desired temperature, and the progress of the reaction is followed by manometric observations and by analysis of samples withdrawn at various stages of the reaction.

The apparatus is shown diagrammatically in Fig. 1. The propane–oxygen mixture is stored over an aqueous glycerol solution in the glass holder *H*; from *H* it passes through the calcium chloride tower *T* and a 1-m. long column of phosphoric oxide *P*, to the graduated mercury gas-holder *M*. From *M* the gases may be transferred to the reaction vessel *R* either directly or by way of the capacity vessel *V*, the latter route being used when it is desired to fill the reaction vessel rapidly to a given pressure. The initial pressure of the medium and the changes of pressure during reaction are indicated by the mercury manometer *G*. By disconnecting the apparatus at the joint *J*, the reaction vessel may be rapidly chilled by plunging it into an ice-water bath, and the reaction arrested at any predetermined time. For visual observation the vessel is placed horizontally in a furnace having a narrow window traversing its whole length (inset, Fig. 1). The reaction vessel *R* is 28 cm. long and 5·5 cm. in diameter, with a capacity of *ca.* 590 c.c., and is made of transparent silica.

Influence of Pressure upon the Inflammation Limits of an Equimolecular Propane–Oxygen Medium.—The higher hydrocarbons have well-defined upper and lower zones of inflammation, the limits of which depend *inter alia* upon the composition of the reacting medium, the size and

nature of the reaction vessel, and the pressure; in studying their combustion, therefore, these limits, which are readily determined for any particular mixture by measuring its spontaneous

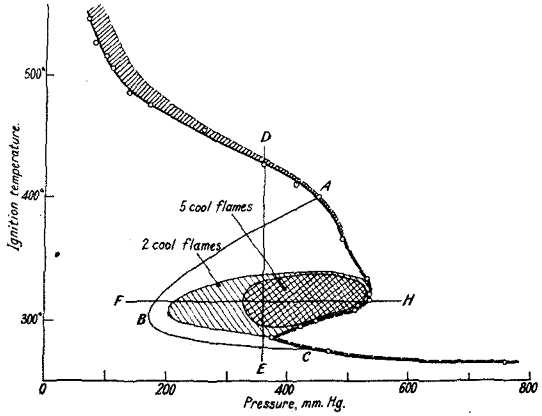
FIG. 1.



ignition temperatures over a sufficiently wide pressure range, can be made to serve as useful reference points.

FIG. 2.

Spontaneous ignition temperatures of a $C_3H_8 + O_2$ *mixture.*



The variations with pressure of the spontaneous ignition temperature of an equimolecular propane–oxygen mixture reacting in a silica vessel are shown by the full-line curve in Fig. 2. It will be seen that below 370 mm. there is only one temperature limit of inflammability, which

decreases with increase of pressure; between 370 and 535 mm. there are three, and above 535 mm. again only one limit, which changes very little with further increase of pressure. At atmospheric pressure, therefore, the mixture in question will always ignite at *ca.* 270°. The area enclosed by the line *ABC* and the ignition curve defines the region in which cool flames are formed during the reaction, although true ignition does not take place.

The general form of the ignition curve is similar to that found by Townend and Chamberlain for propane–air mixtures (*loc. cit.*), but the pressure limits differ widely in accordance with the greater reactivity of the medium.

From the standpoint of the mechanism of propane oxidation, special interest attaches to the changes occurring on traversing an isobaric line such as *DE* from low to high temperatures and an isothermal line such as *FH* from low to high pressures. The reactions under the conditions of temperature and pressure defined by these lines are in all cases accompanied by visible luminescence, and, within certain limits, by the formation of cool flames or by true ignition. The sequence of changes occurring in order of increasing temperature are described below.

Visual Observations along the 360-*mm. Isobar and the* 315° *Isotherm.*—The following observations were made with an equimolecular propane–oxygen medium reacting at 360 mm. and various temperatures in a transparent silica vessel placed in the horizontal furnace (Fig. 1, inset). The experiments were carried out in a darkened room.

Temp. range.	Observations.
275—285°	After an induction period of several minutes, a faint luminosity develops and remains until reaction is substantially complete.
290	A faint luminosity develops, followed by a pale blue cool flame which starts near the centre of the vessel and spreads outwards, giving rise to a slight pressure pulse; the luminosity persists for some seconds after the passage of the flame.
300—340	The initial luminosity observed immediately on filling the vessel is succeeded by 4 or 5 separate cool flames at intervals of several seconds. Each of these flames traverses the whole vessel before extinction.
340	Two cool flames only are formed.
345—385	Over this range only one cool flame is observed. The intensity of the cool flames increases as their number diminishes, and in all cases the flames are succeeded by an intense uniform glow persisting for some seconds. Between 350° and 385° the single cool flames diminish in intensity whilst the general luminescence increases until eventually it becomes impossible to distinguish the flames.
380—425	Intense luminosity develops immediately on filling with the mixture; at 425° it is succeeded by a bright blue flame which at a slightly higher temperature changes to the characteristic yellow flame, usually associated with true ignition. The narrow shaded strip adjacent to the ignition curve in Fig. 2 defines the region in which these blue flames are formed.

On traversing an isothermal line at 315° the observed phenomena are similar to those described above; the number of cool flames first increases from one at 180 mm. to four or five at 321—520 mm. and then diminishes. It is noteworthy that true ignition at about 530 mm. will sometimes occur after an interval of several seconds succeeding the passage of one or two separate cool flames, and that under our experimental conditions it is usually accompanied by carbon deposition in the cool-flame region.

From the foregoing, and other supplementary experiments, the boundaries of the zones in which multi-cool flames are formed have been determined and are indicated in Fig. 2 by the system of closed curves in the cool flame area.

It is not yet profitable to discuss the origin of cool flames in detail, but their occurrence and properties suggest some change in the medium associated with a reaction of the chain type, accompanied by the liberation of radiant energy, possibly from a highly activated intermediate product. A study of the changes in composition of the medium during their passage should therefore furnish information as to the conditions pertaining to their initiation and propagation.

During the slow combustion of propane there is formed, in addition to the two oxides of carbon and steam, a large number of intermediate products of which the more important are aldehydes, peroxidic substances, acids, and propylene. Smaller quantities of polymerised olefins, acetylene, methane, and hydrogen can also usually be detected. A complete quantitative analysis of such a mixture presents considerable difficulty, but it is possible to obtain a fairly accurate estimate of all the gaseous products, the higher aldehydes and formaldehyde, the total peroxidic substances, the total acids, and in some instances, the total alcohols and methyl alcohol. In this manner upwards of 90% of the carbon of the propane burnt has usually been accounted for in our experiments. By assuming the balance to consist of polymerised propylene $(C_3H_6)_n$, the

FIG. 3.

Products from the combustion of a C_3H_8 + O_2 medium at 460 mm. and 274°.

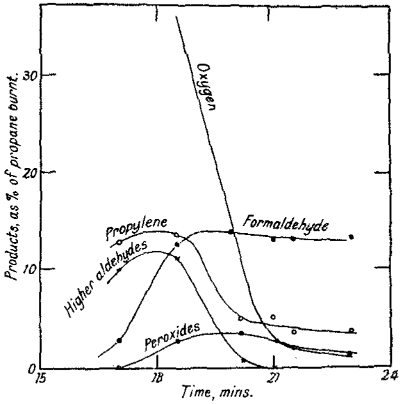
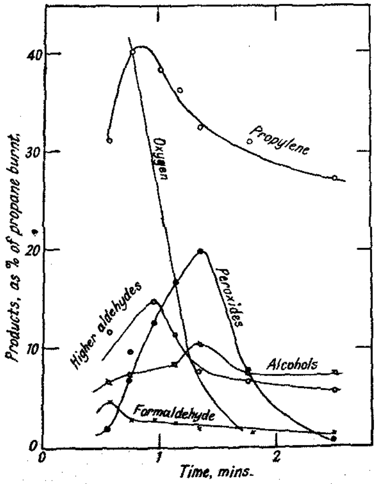


FIG. 4.

Products from the combustion of a C_3H_8 + O_2 medium at 360 mm. and 400°.

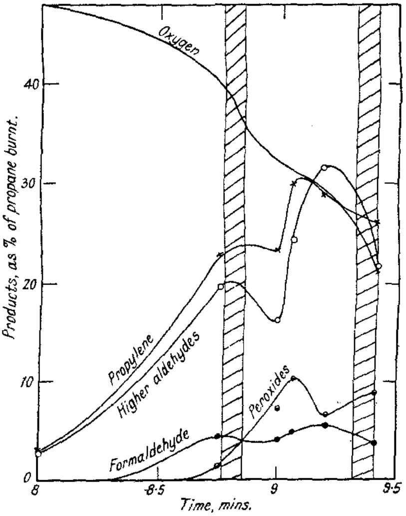


residual hydrogen and oxygen are found to be approximately in the ratio required for water formation (*i.e.*, 1 : 8).

In following the changes in composition of the reacting medium during a slow oxidation, the method employed consists in first obtaining by manometric observations and analyses a pressure-time record of the complete reaction, and then carrying out a series of experiments under precisely similar conditions but arresting the reaction at various intermediate stages by removing the vessel from the furnace and rapidly cooling it. The products are subsequently analysed by methods described later.

Fig. 5.

Products from the reaction of a $C_3H_8 + O_2$ medium at 400 mm. and 294°.



To investigate the conditions of cool flame propagation, we have selected an equimolecular propane–oxygen mixture and have so adjusted the reaction temperatures and pressures as to obtain (*a*) slow combustion below the cool flame zone (460 mm. and 274°), (*b*) slow combustion above the cool flame zone (360 mm. and 400°), and (*c*) combustion in the cool flame zone giving four cool flames (400 mm. and 294°). The curves in Figs. 3, 4, and 5 show the distribution of the carbon of the propane burnt amongst the products, and the corresponding analytical data are in Tables I, II, and III.

We consider first the slow reaction below the cool flame zone (Table I, Fig. 3). There is an induction period of 15 minutes, during which no detectable pressure change takes place, followed by a reaction period of 7 minutes. At the outset of reaction the medium contains propylene, acetylene, methane, carbon monoxide, and higher aldehydes, together with traces of carbon dioxide, formaldehyde, peroxides, and acids. As reaction proceeds, the proportions of acetylene, propylene, methane, and higher aldehydes diminish progressively, whilst those of the oxides of carbon and formaldehyde increase. The acids and peroxides increase to a maximum, but whereas the former remain fairly constant during the final stages of the reaction, the latter diminish. It should be noted that the peroxide maximum occurs at an appreciable time interval after the higher aldehyde maximum. The ratio oxygen : propane used changes from 0·5 at the beginning of reaction to 2·0 at its close.

TABLE I.—*Products from the combustion of a $C_3H_8 + O_2$ mixture at 274° and 460 mm. pressure.*

Duration of induction = 15 mins.; duration of reaction = 7 mins.

Expt. No.	1.	2.	3.	4.	5.	6.
Time of sampling, in mins. from start	16·0	17·3	19·1	20·0	20·3	22·0
Oxygen content of sample, %	46·3	36·7	11·2	2·8	1·6	1·1
Products as percentages of the carbon of the propane burnt: C_3H_6	12·8	5·4	1·1	2·1	1·8	1·8
C_2H_4	12·8	13·5	4·8	5·0	3·4	3·3
CO	17·2	15·4	21·0	28·0	26·4	27·4
CO_2	2·8	11·1	13·7	13·0	13·3	13·2
CH_4	20·7	9·3	5·3	3·0	4·5	2·9
Acids	1·9	6·2	4·3	3·4	3·6	3·6
Higher aldehydes	10·0	12·6	0·3	0·5	nil	nil
Formaldehyde	2·7	6·8	8·4	7·3	8·1	8·2
Peroxides	nil	2·6	3·2	2·6	1·8	0·8
Ratio O_2/C_3H_8 consumed	0·52	1·50	1·77	1·87	2·00	2·00

C–H_2–O_2 balances.	1. C.	1. H_2.	1. O_2.	2. C.	2. H_2.	2. O_2.	3. C.	3. H_2.	3. O_2.
Units in original mixture	3140	697	2772	3140	697	2772	3140	697	2772
Units in above products	3023	672	2752	3018	643	2403	2635	487	1500
Differences	117	25	20	122	54	369	505	211	1272
Calculated as $(C_2H_4)_x$	117	19	—	122	20	—	505	84	—
Leaving as H_2O	—	6	20	—	34	369	—	127	1272
Ratio of residual H_2/O_2		1 : 3			1 : 10·8			1 : 10	

C–H_2–O_2 balances.	4. C.	4. H_2.	4. O_2.	5. C.	5. H_2.	5. O_2.	6. C.	6. H_2.	6. O_2.
Units in original mixture	3140	697	2772	3140	697	2772	3140	697	2772
Units in above products	2546	436	1541	2564	431	1399	2551	407	1383
Differences	594	261	1231	576	266	1373	589	290	1389
Calculated as $(C_2H_4)_x$	594	99	—	576	96	—	589	98	—
Leaving as H_2O	—	132	1231	—	170	1373	—	192	1389
Ratio of residual H_2/O_2		1 : 9·3			1 : 8·1			1 : 7·2	

TABLE II.—*Products from the combustion of a $C_3H_8 + O_2$ mixture at 400° and 360 mm. pressure.*

Duration of induction = 10—15 secs.; duration of reaction = 2 mins. 35 secs.

Expt. No.	7.	8.	9.	10.	11.	12.	13.
Time of sampling, in secs. from start	33	44	57	68	80	105	150
Oxygen content of sample, %	47·5	39·0	30·0	18·0	6·85	1·8	1·9
Products as percentages of the carbon of the propane burnt: C_3H_6	6·3	4·7	3·1	2·1	2·3	2·3	2·6
C_2H_4	31·1	40·1	38·2	36·3	32·5	31·0	27·3
CO	15·3	16·6	22·4	25·5	30·3	33·2	35·4
CO_2	0·9	2·6	4·8	3·8	4·4	4·7	5·2
CH_4	8·4	6·8	5·7	5·0	3·9	3·5	5·7
Higher aldehydes	11·7	9·4	14·5	11·3	7·6	6·6	5·6
Formaldehyde	4·6	2·6	2·8	2·1	1·9	1·3	1·3
Peroxides	1·9	6·8	12·6	16·9	19·9	7·7	0·5
Methyl alcohol	nil	1·8	3·0	4·2	5·7	6·2	6·1
Higher alcohols	6·7	4·5	4·2	3·9	4·5	1·2	1·2
Ratio O_2/C_3H_8 consumed	0·71	1·26	1·55	1·72	1·93	1·92	1·89

C–H_2–O_2 balances.	7. C.	7. H_2.	7. O_2.	8. C.	8. H_2.	8. O_2.	9. C.	9. H_2.	9. O_2.	10. C.	10. H_2.	10. O_2.
Units in original mixture	2000	445	1922	2000	445	1922	2000	445	1922	2000	445	1922
Units in above products	1957	418	1856	1942	397	1594	1993	394	1535	1954	373	1319
Differences	43	27	66	58	48	328	7	51	387	46	72	603
Calculated as $(C_2H_4)_x$	43	7	—	58	9	—	7	1	—	46	7	—
Leaving as H_2O	—	20	66	—	39	328	—	50	387	—	65	603
Ratio of residual H_2/O_2		1 : 3·3			1 : 8·4			1 : 7·7			1 : 9·3	

C–H_2–O_2 balances.	11. C.	11. H_2.	11. O_2.	12. C.	12. H_2.	12. O_2.	13. C.	13. H_2.	13. O_2.
Units in original mixture	2000	445	1922	2000	445	1922	2000	445	1922
Units in above products	1932	350	1169	1888	320	954	1970	321	898
Differences	68	95	753	112	125	968	30	124	1024
Calculated as $(C_2H_4)_x$	68	11	—	112	18	—	30	5	—
Leaving as H_2O	—	84	753	—	107	968	—	119	1024
Ratio of residual H_2/O_2		1 : 9·0			1 : 9·0			1 8·6	

TABLE III.—*Products from the combustion of a $C_3H_8 + O_2$ mixture at 294° and 400 mm. pressure.*

Duration of induction = 8 mins.; duration of reaction = 3 mins.

Expt. No.	14.	15.	16.	17.	18.	19.
Time of sampling, in secs. from the start	480	525	540	544	552	565
Oxygen content of sample, %	50·2	42·0	36·1	33·7	33·0	25·0
Products as percentages of the carbon of the propane burnt: C_3H_6	3·7	22·9	23·4	30·0	28·8	26·0
CO	8·6	14·6	15·8	17·5	18·7	20·0
CO_2	0·8	4·7	4·0	2·4	5·0	5·0
Acids	2·8	13·0	11·1	10·9	10·0	9·2
Higher aldehydes	3·0	19·6	16·1	24·3	31·6	19·6
Formaldehyde	nil	4·4	4·1	4·9	5·5	3·9
Peroxides	nil	1·4	6·2	8·2	6·9	8·8
Ratio O_2/C_3H_8 consumed	0·24	1·05	1·14	1·40	1·37	1·52

C–H_2–O_2 balances.	14. C.	14. H_2.	14. O_2.	15. C.	15. H_2.	15. O_2.	16. C.	16. H_2.	16. O_2.	17. C.	17. H_2.	17. O_2.	18. C.	18. H_2.	18. O_2.	19. C.	19. H_2.	19. O_2.
Units in original mixture	2585	574	2389	2585	574	2389	2585	574	2389	2585	574	2389	2585	574	2389	2585	574	2389
Units in above products	2336	498	2379	2491	534	2404	2389	492	2152	2536	510	2066	2583	527	2175	2419	461	1841
Differences	249	76	10	94	40	+15	196	82	237	49	64	323	2	47	314	166	113	548

TABLE IV.—*Products from the combustion of a $C_3H_8 + O_2$ mixture at 360 mm. pressure and various temperatures.*

Expt. No.	20.	21.	22.	23.	24.
Reaction temp.	280°	310°	355°	380°	400°
Oxygen content of sample, %	1·3	3·2	4·9	2·3	6·9
Products as percentages of the carbon of the propane burnt: C_2H_2	2·7	4·0	4·5	3·8	2·3
C_3H_6	3·3	14·8	28·5	39·5	32·5
CO	22·9	26·5	31·9	39·5	30·3
CO_2	9·4	5·4	5·7	5·6	4·4
CH_4	4·8	2·7	3·3	5·6	3·9
Acids	1·8	6·9	2·6	3·0	—
Higher aldehydes	3·2	8·2	3·0	2·5	7·5
Formaldehyde	3·3	5·8	4·2	4·0	1·9
Peroxides	1·9	14·7	21·5	22·1	19·9
Ratio O_2/C_3H_8 consumed	1·78	2·05	2·38	2·40	1·97

C–H_2–O_2 balances.	20. C.	20. H_2.	20. O_2.	21. C.	21. H_2.	21. O_2.	22. C.	22. H_2.	22. O_2.	23. C.	23. H_2.	23. O_2.	24. C.	24. H_2.	24. O_2.
Units in original mixture	2430	540	2148	2030	451	2000	1847	410	1842	1773	394	1772	2000	445	1922
Units in above products	1784	296	922	1774	302	1046	1712	307	936	1703	314	933	1829	325	1062
Differences	646	244	1226	256	149	954	135	103	906	70	80	839	171	120	860
Calculated as $(C_2H_4)_x$	646	108	—	256	43	—	135	22	—	70	11	—	171	28	—
Leaving as H_2O	—	136	1226	—	106	954	—	81	906	—	69	839	—	92	860
Ratio of residual H_2/O_2		1 : 9·0			1 : 9·0			1 : 9·0			1 : 12·1			1 : 9·3	

In the carbon–hydrogen–oxygen balance a small deficit of carbon is found in Expt. 1, increasing in magnitude as reaction proceeds. This we believe to be due in part to the formation of a liquid polymer of propylene, traces of which are always present in the reaction vessel after an experiment; and on this assumption the oxygen and hydrogen unaccounted for in the products are found to be approximately in the proportions for water formation.

Considering next the slow reaction above the cool-flame zone (Table II, Fig. 4), we find an induction period of only 10—15 secs., followed by a reaction period of 2·5 mins. during which intense luminescence is visible. The products formed are the same as at the lower temperature, but the relative proportions in which they occur are very different. In the gaseous products it will be seen that upwards of 30% of the carbon of the propane burnt appears as propylene at all stages of the reaction; both acetylene and methane are also found throughout, diminishing in quantity as reaction approaches completion; traces of hydrogen (less than 1%) are also present. Amongst the liquid products, peroxides and aldehydes appear in much larger proportions than in the low-temperature experiment; the peroxides reach a maximum when reaction is proceeding with maximum velocity, and represent at this stage no less than 19·9% of the carbon of the propane burnt. The higher aldehydes reach a maximum somewhat earlier, whilst formaldehyde, present at the commencement of reaction to the extent of 4·6%, progressively diminishes as reaction proceeds.

Estimates were also made of the methyl and higher alcohols present, the latter consisting principally of ethyl with only small quantities of *n*-propyl alcohol. The concentration of total alcohols reaches a maximum at approximately the same time as do those of the peroxides, but later diminishes at a slower rate. At the end of reaction the liquid products consist mainly of higher aldehydes and methyl alcohol. The carbon–oxygen–hydrogen balances indicate that practically the whole of the carbon of the propane burnt is accounted for in the products.

In the third series (Fig. 5 and Table III) in the cool-flame zone, analyses have been made up to and including the second cool flame only; beyond this point the rate of reaction is too high, and the intervals between the third and fourth flame too short, to permit of sampling at intermediate points. The induction period for the reaction was 8 mins., and the total reaction time 3 mins., the first cool flame being observed after 8·75 mins. and the second after 9·4 mins.; in Fig. 5, the two shaded areas mark approximately the position and duration of the cool flames.

Although the changes occurring during this reaction are rather complex, it is possible to correlate them to some extent with the cool-flame phenomena. Thus the analytical figures show that higher aldehydes, acids, propylene, and carbon monoxide are present in detectable quantities at the outset of the reaction, but no peroxides or formaldehyde and only a trace of carbon dioxide. The higher aldehydes rise to a first maximum 45 secs. after reaction starts, and at this point the first cool flame is observed; during its propagation the percentage of higher aldehydes diminishes whilst peroxides and formaldehyde begin to appear; the rate of oxidation of the propane also increases.

Shortly after the extinction of the cool flame, the peroxide content of the medium reaches a first maximum, whilst the higher aldehydes fall to a minimum; a little later the aldehydes again increase rapidly to a second maximum, higher than the first, whilst the peroxides simultaneously decrease; the second cool-flame ignition then takes place and is accompanied by changes in the products similar to those noted with the first flame.

Between the two cool-flame ignitions there is a second short induction period during which the pressure remains substantially constant and little oxygen is consumed. The rate of formation of propylene appears to follow that of the higher aldehydes at all stages, whilst carbon monoxide increases fairly uniformly throughout.

The carbon–hydrogen–oxygen balances are less concordant than in the previous series, but show that upwards of 85% of the carbon of the propane burnt has been accounted for.

A comparable series of experiments in the cool-flame zone with a propane–oxygen–nitrogen (1 : 1 : 2) medium at 290° and 760 mm. reacting to give two cool flames only, gave results agreeing in all important particulars with those described above. General agreement is also shown with the results of Aivazov and Neumann for pentane–oxygen mixtures giving a single cool flame (*Acta Physicochim.*, 1936, **4**, 575).

On the basis of the above experiments, we conclude that a necessary condition for cool-flame inflammation is a critical high concentration of higher aldehydes; during the passage of the flame the aldehydes are further oxidised to give aldehyde peroxides and/or per-acids and ultimately formaldehyde. The reactions by which propylene and the higher aldehydes are formed also appear to be related.

Aivazov and Neumann, on the other hand, adopt the view that cool flames are formed when

the peroxides *and* aldehydes reach a certain critical concentration. In this connection it may be recalled that Pease found (*loc. cit.*) that when he coated the walls of his reaction vessel with potassium chloride, the peroxide content of the medium was diminished without materially altering the rate of reaction. We have confirmed this observation and find, moreover, that whilst in such circumstances peroxides can only be detected in traces in the medium, cool flames may nevertheless readily be formed and propagated in it.

We have, however, not yet been able to isolate or identify any of the peroxidic substances present, but find that on decomposition by concentrated potassium hydroxide solution they liberate a gas consisting of hydrogen, 80; oxygen, 20%. These proportions do not correspond with the behaviour of any known simple peroxide, but indicate the existence of a mixture containing possibly an alkyl peroxide, a per-acid, and/or hydrogen peroxide. Qualitative tests show the last to be present in traces.

There is also evidence in our experiments that the general luminosity which is observed in the slow combustion at low temperatures and attains its maximum intensity during the slow combustion at high temperatures (where cool flames are not formed) is associated with a change in the concentration of the peroxidic substances present. In this connection attention may be directed to the comparatively high concentration of peroxidic substances in the medium during reaction in the high-temperature, slow-combustion region. It therefore seems probable that, although the initial stages of the propane combustion result in the formation of higher aldehydes by a simple mechanism, yet the rate of its further oxidation is determined by the thermal stability of some intermediate product, probably a peroxide or per-acid. Further evidence in support of this view will be found in Part III.

To complete this section of the work, a series of experiments was carried out on the 360-mm. isobar at various temperatures between 280° and 400°, and samples were taken at corresponding points towards the end of reaction whilst some oxygen still remained unburnt; in the experiments in the cool-flame zone the samples were taken after the passage of the last cool flame. The data, summarised in Table IV, show that with increase of temperature the percentages of peroxide and carbon monoxide surviving increase throughout the series, whilst the aldehydes and acids tend to a maximum in the cool-flame zone. Attention may also be directed to the changes occurring in the amounts of propylene, acetylene, and methane surviving. The propylene reaches a maximum at the upper limit of the cool-flame zone when comparatively large quantities of higher aldehydes are formed at an early stage of the reaction; acetylene and methane are also present in maximum concentration in the same region.

Although both the last-named gases may arise from the pyrolysis of propane or propylene, the temperature required for their formation by this means is usually upwards of 600°. If, however, propylene is formed from propane by the stabilisation of some radical taking part in the reaction, the possibility exists of a simultaneous partial breakdown of the radical to give both gases in equimolecular proportion, *e.g.*, according to the atomic chain mechanism recently suggested by Norrish:

$$C_3H_8 + O = CH_3{\cdot}CH_2{\cdot}CH\colon + H_2O \quad . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

$$CH_3{\cdot}CH_2{\cdot}CH\colon = CH_3{\cdot}CH\colon CH_2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (2)$$

and

$$CH_3{\cdot}CH\colon CH_2 = CH_4 + C_2H_2 \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (3)$$

A more detailed discussion of the bearing of these results upon the mechanism of the combustion will be found in Part III.

Analysis of the Products.—The gaseous products were analysed for carbon dioxide, acetylene, oxygen, olefins, and carbon monoxide by absorption with the usual reagents, and for propane, methane, and hydrogen by combustion over copper oxide followed by explosion with excess of oxygen. The unsaturated hydrocarbons were identified by preparing their bromine addition derivatives, and in the case of acetylene by preparing silver acetylide, which was subsequently decomposed with dilute acid and the gas estimated by absorption; they were found to consist of propylene and acetylene only.

The condensable and soluble liquid products were estimated by standard methods which were all tested with known mixtures of the various constituents: *Acids.* By titration with N/100-baryta solution. *Total aldehydes.* With hydroxylamine hydrochloride, a correction being applied for the acid content of the products. *Formaldehyde.* By a colorimetric method using Schiff's reagent, with the addition of concentrated sulphuric acid to suppress the colour due to higher aldehydes. *Higher aldehydes.* By difference. *Peroxides.* By a colorimetric method with 5% titanium chloride solution, standards freshly prepared with hydrogen peroxide being

used for comparison. *Total alcohols.* Aldehydes were destroyed by heating with 1 c.c. of hydrogen peroxide (20-vol.) and 5 c.c. of 10% sodium hydroxide in a pressure bottle; the resulting solution was distilled, and the distillate divided into two parts. One part was oxidised with 25 c.c. of N/10-potassium dichromate + 1 c.c. of 50% sulphuric acid, and the amount of oxidising agent used was determined by addition of potassium iodide and estimation of the amount of iodine liberated. (Under these conditions the reaction was found to proceed to the acid stage only for methyl and ethyl alcohols.) The second part was used for the estimation of methyl alcohol; it was oxidised in the cold for 2 mins. with 5 c.c. of acid permanganate solution, the excess being then removed by addition of 1 c.c. of oxalic acid solution; 5 c.c. of Schiff's reagent were added, and the colour developed compared after 10 mins. with that of a series of standards similarly prepared from pure methyl alcohol.

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349. *The Oxidation of Propane. Part II. The Products of the Slow Oxidation at High Pressures.*

By D. M. NEWITT and W. G. SCHMIDT.

It is shown that when propane is oxidised at high pressures, *iso*propyl alcohol and acetone are found in the products in circumstances suggesting that they arise from direct oxidation of the hydrocarbon molecule at the β-carbon atom.

n-Propyl, ethyl, and methyl alcohols are also formed in considerable quantities, the yield of the higher alcohols being favoured by increase of pressure.

The results suggest that propane undergoes oxidation in two ways, the initial products in the one case being *n*-propyl alcohol and propaldehyde, and in the other, *iso*propyl alcohol and acetone.

IN Part I (preceding paper) it is shown *inter alia* that, in the oxidation of propane at and below atmospheric pressure, higher aldehydes of the type R·CHO are important intermediates, which, in certain circumstances, may exert a marked influence upon the course of the oxidation and give rise to the phenomenon of cool-flame combustion. The actual mechanism by which they are formed from the parent hydrocarbon is still open to question, but their occurrence in large quantities affords strong evidence that the point of initial oxygen attack on the propane molecule is at a terminal carbon atom.

When, however, propane is oxidised at high pressures the products are found to contain, in addition to most of those substances formed at normal pressures, both *iso*propyl alcohol and acetone, arising probably from some initial oxidation at the β-carbon atom. Although the rôle of pressure in bringing about such an alteration in the primary process is not obvious, there are several ways in which it might operate indirectly; *e.g.*, a sufficiently high pressure might alter the ratio of the collision period leading to activation and the vibrational periods of the C–C or C–H linkages; or, it might act by increasing the concentration of certain secondary products formed reversibly by the interaction of intermediates taking part in the main combustion process. The work described in the present paper was carried out with a view to obtain more detailed information upon its action.

EXPERIMENTAL.

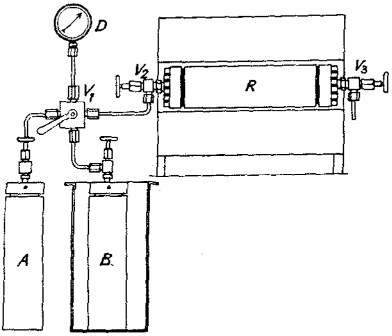
In following the progress of a highly exothermic reaction such as the oxidation of propane, it is necessary, if substantially isothermal conditions are to be maintained, to employ media containing a large excess of one or other of the reactants and/or of an inert diluent gas or vapour, and preferably to use a static method similar to that described in Part I.

The apparatus shown diagrammatically in the figure was used. The reactants and diluent gases are stored under pressure in the steel cylinders *A* and *B*, and are admitted separately through the valves V_1 and V_2 to the steel reaction vessel *R*, which is maintained at the desired temperature by external heating. Reaction normally takes place slowly with a rise of temperature seldom exceeding about 10°; on completion, the products are discharged through the exit

valve V_3, and, after traversing a series of cooling coils and scrubbers in which the condensable and water-soluble products are removed, are collected in a calibrated gas-holder.

The pressure of the system is measured by the Bourdon gauge *D*, and the reaction temperature by means of a platinum–rhodium thermocouple situated in a light steel tube traversing axially the reaction chamber. In experiments employing high partial pressures of propane, the storage cylinders and all connections to the reaction vessel have to be maintained at a temperature sufficiently high to avoid condensation.

The Products from the Slow Oxidation at High Pressures.—From the slow reaction at pressures above about 10 atm., there results a complex mixture of liquid and gaseous products containing formaldehyde and higher aldehydes, normal alcohols, and *iso*propyl alcohol, acetone, the two oxides of carbon, and steam. No propylene, methane, or acetylene is found amongst the gases, and usually no peroxidic substance in the condensable liquid products. In experiments in which the contents of the reaction vessel were suddenly released before the end of reaction and were immediately cooled, traces of peroxides could, however, sometimes be detected by the titanium chloride test, but no unsaturated gases, methane, or hydrogen.



It is also noteworthy that the products from mixtures containing a large excess of propane reacting in the neighbourhood of their ignition temperatures are always found to contain considerable quantities of naphthalene, which condenses in the exit valve and cooling coils as a white solid.

Qualitative tests show the higher aldehydes to consist of propaldehyde and acetaldehyde, and the *n*-alcohols of methyl, ethyl, and propyl alcohol. The acids consist principally of acetic, with traces of propionic and possibly formic acid, although no derivatives of the last were prepared. In the tabulated results, quantitative estimates are given only for the total aldehydes, *n*-alcohols, and acids.

The Influence of Temperature upon the Distribution of Oxygen in the Products.—To ascertain the most favourable conditions for examining the pressure effect, a series of experiments was first carried out with a 1 : 5 propane–air medium at 30 atm. over a range of temperature giving from very slow to rapid rates of reaction without, however, approaching ignition; at each temperature the products were collected at the end of the reaction, when little or no free oxygen remained, and were subsequently analysed, with the results recorded in Table I.

The data show that, although the total *n*-alcohols surviving in the products increase throughout with temperature, yet the total aldehydes, *iso*propyl alcohol, and acids reach a maximum and then diminish; the ratio of the sum of the aldehydes and *n*-alcohols, *A*, to the *iso*propyl alcohol and acetone, *B*, which may be taken as a rough measure of the relative extent to which the β-carbon atom and the terminal carbon atoms are undergoing oxidation, shows a minimum at about 274°.

By a suitable adjustment of temperature and pressure it is possible to establish a cool flame in the 1 : 5 mixture and to compare the resultant products with those from slow combustion

TABLE I.

Products from the reaction of a 1 : 5 *propane–air medium at* 30 *atm. and various temperatures.*

Temp.	260°.	270°.	274°.	284°.	286°.
	Products, as % of the carbon of the propane burnt.				
Total aldehyde	5·7	8·8	12·8	16·6	8·7
Total *n*-alcohols	20·9	25·5	18·8	25·5	40·0
*iso*Propyl alcohol	2·0	6·9	12·7 }	8·4	6·2
Acetone	nil	1·4	0·6 }		0·5
Total acids	4·4	13·4	13·8	11·5	6·0
CO_2	49·8	25·0	26·9	13·0	11·0
CO	17·2	19·0	14·4	25·0	27·6
Ratio CO/CO_2	0·35	0·76	0·53	1·9	2·5
Ratio A/B *	13·3	4·2	2·4	5·0	7·3

* A = Sum of the aldehyde and *n*-alcohols; B = sum of the *iso*propyl alcohol and acetone.

under approximately the same conditions. The data for two such experiments at 30 atm. are given below:

	Products, as % of the carbon of the propane burnt in	
	Slow combustion.	Cool-flame combustion.
Total aldehydes	8·8	22·2
n-Alcohol	25·5	22·1
*iso*Propyl alcohol	6·9	4·2
Acetone	1·4	1·7
Acids	13·4	6·8
CO_2	25·0	20·4
CO	19·0	12·6

The only marked difference in the products lies in the increased quantity of total aldehydes formed in the cool-flame combustion.

The Influence of Pressure.—To obtain a true comparison of the changes in the products resulting from a progressive increase of pressure, the above results show that it is necessary to adjust the temperatures so that reaction at the different pressures will take place at approximately equal rates. In Table II the analytical data for a 1 : 3·6 propane–air medium reacting at four pressures in the range 1—100 atm. and temperatures between 373° and 250° are summarised.

TABLE II.

Products from the reaction of a 1 : 3·6 *propane–air medium at pressures from* 1 *to* 100 *atm.*

Pressure, atm.	1	20	60	100
Reaction temp.	373°	281°	252°	250°
	Products, as % of the carbon of the propane burnt.			
Total aldehydes	20·5	21·8	13·5	13·7
n-Alcohols	19·7	21·0	17·5	15·2
*iso*Propyl alcohol	1·3	2·8	6·2	16·0
Acetone	0·5	4·3	12·5	7·9
Acids	4·3	17·0	19·0	18·9
CO_2	7·3	17·1	21·4	20·6
CO	21·3	16·0	9·9	7·7
C_3H_6	25·1	nil	nil	nil
Ratio CO/CO_2	2·93	0·95	0·46	0·37
Ratio A/B	22·3	6·0	1·7	1·2

The effect of pressure is shown by the rapid diminution of the ratio A/B between 1 and 60 atm.; there is clearly an increasing tendency as the pressure is raised for the propane molecule to undergo primary oxidation at the β-carbon atom, and the quantities of *iso*propyl alcohol and acetone surviving show a corresponding increase. It should also be noted that propylene, present to the extent of 25% at atmospheric pressure, is entirely absent at high pressure.

Carbon monoxide, formed partly from the thermal decomposition of aldehydes and partly from their further oxidation, decreases with increase of pressure and lowering of the reaction temperature.

The Influence of Concentration.—In the slow oxidation of methane and ethane at high pressures, the concentration of the hydrocarbon has been shown to play an important part in determining the survival of intermediate products (*Proc. Roy. Soc.*, **1931**, *A*, **134**, 591; **1933**, *A*,

140, 426), and from structural and other considerations a still greater effect might be anticipated in the case of propane. Experiments at 30 atm. and 275° with a series of mixtures in which the proportions of propane to air are varied between 1 : 20 and 1 : 0·5 confirm this prediction.

In the results set forth in Table III the most noticeable feature is the extent to which the

TABLE III.

Products from the reaction of various propane–air mixtures at 30 atm. pressure and 275°.

Propane : air.	1 : 20.	1 : 5.	1 : 3·6.	1 : 2·5.	1 : 1·25.	1 : 0·7.	1 : 0·5.
	Products, as % of the carbon of the propane burnt.						
Total aldehydes	12·5	8·8	12·0	18·5	16·1	14·6	16·7
n-Alcohols	17·3	25·5	23·0	27·6	33·1	34·8	34·5
*iso*Propyl alcohol	2·7	6·9	5·2	2·8	5·2	6·0	14·4
Acetone	1·2	1·4	1·3	0·9	0·3	10·6	7·4
Acids	13·9	13·4	15·2	6·7	8·9	11·0	12·5
CO_2	31·5	25·0	22·1	8·6	10·5	9·8	7·0
CO	20·9	19·0	21·3	34·8	25·9	13·6	8·0
Total condensable products	47·6	56·0	56·7	56·5	63·6	77·0	85·5
Ratio CO/CO_2	0·66	0·76	0·96	4·05	2·46	1·39	1·14
Ratio A/B	7·6	4·1	5·4	12·4	9·0	2·9	2·4

total condensable products increase with the concentration of the hydrocarbon. For instance, whereas with a 1 : 20 propane–air mixture they represent 47·6% of the carbon of the propane burnt, yet when the proportion of propane is increased to 1 : 0·5 the corresponding figure is 85·5%.

Under comparable conditions in respect of concentration, pressure, and reaction velocity, the yields from methane, ethane, and propane respectively are as follows :

	CH_4.	C_2H_6.	C_3H_8.
Reaction temp.	380°	305°	275°
Total condensable products, as % of the carbon of the hydrocarbon burnt	7	40	64

n-Alcohols are in all cases present in larger quantities than either *iso*propyl alcohol, aldehydes, or ketones, but the change in the ratio (aldehyde + *n*-alcohol) : (acetone + *iso*propyl alcohol) shows that with increasing concentrations of the hydrocarbon a greater proportion of the oxygen is utilised in oxidising it at the β-carbon atom.

The Distribution of Alcohols in the Products.—Further light is thrown on the mechanism of the oxidation by a more detailed study of the effect of pressure upon the distribution of alcohols in the products. The absolute amount of alcohols recovered from any one experiment in our apparatus is not large, and in order to obtain a sufficient quantity for analysis, it is necessary to carry out 10—20 experiments at each pressure. The products are freed from aldehyde, and the individual alcohols estimated by a method based upon their relative solubilities in aqueous calcium chloride and in xylene. The results for a 1 : 3·6 propane–air mixture at 5, 30, and 65 atm. are given below.

Relative quantities of alcohols surviving from the reaction of a 1 : 3·6 propane–air mixture.

Pressure, atm.		5	30		65
Products	Methyl alcohol	76·3	58·0	55·3	50·1
	Ethyl alcohol	19·1	17·6	13·2	9·8
	Propyl alcohol	4·6	4·3	7·3	12·2
	*iso*Propyl alcohol		20·0	24·2	27·9

The results at 5 atm. confirm Pease's observation (*J. Amer. Chem. Soc.*, 1934, **56**, 2034) that methyl alcohol is the chief constituent of the alcoholic products at low pressures. As the pressure is increased, the proportions of both methyl and ethyl alcohol diminish, whilst those of propyl and *iso*propyl alcohol increase. The formation of a series of *n*-alcohols from propane is explicable on the assumption that oxidation takes place at an end methyl group, the propyl alcohol formed in the initial stages then undergoing further oxidation to propaldehyde, and the lower alcohols being subsequently formed by the reaction $R{\cdot}CHO + O_2 = R{\cdot}OH + CO_2$.

Evidence in support of this mechanism is obtained from experiments upon the slow oxidation of propyl and ethyl alcohol severally at high pressure. The former reacting at 240° and 56 atm. gives propaldehyde, acetaldehyde, ethyl alcohol, and propionic and acetic acids, whilst the latter reacting at 280° and 50 atm. gives acetaldehyde, methyl alcohol, and acetic and formic acids

(*Proc. Roy. Soc.*, **1934**, *A*, **147**, 555). It will also be recalled that Kane, Chamberlain, and Townend (this vol., p. 436) have shown that methyl alcohol is far less easily oxidisable than either propyl or ethyl alcohol even at high pressures, and its survival in comparatively large quantities is therefore to be expected.

The formation of *iso*propyl alcohol might be attributed to hydration of propylene: $C_3H_6 + H_2O = CHMe_2{\cdot}OH$, but at 250—300° the equilibrium constants for the reaction would demand the presence of considerable quantities of propylene, which, in point of fact, was absent in the high-pressure experiments. We conclude, therefore, that, in addition to attack at the terminal carbon atom, the propane molecule may undergo direct oxidation at the β-carbon atom, a process which is favoured by high pressure:

$$\begin{array}{ccccccccc} CH_3 & & CH_3 & & CH_3 & & CH_3 & & CH_3 \\ CH_2 & \longleftarrow & CH_2 & \longleftarrow & CH_2 & \longrightarrow & CH{\cdot}OH & \longrightarrow & CO \\ CHO & & CH_2{\cdot}OH & & CH_3 & & CH_3 & & CH_3 \end{array}$$

Analytical Methods.—The methods for estimating total aldehydes, alcohols, and acids have been described in Part I. In addition the following were used.

Alcohols. The products were freed from aldehydes by the addition of hydroxylamine hydrochloride, potassium hydroxide was added, and the alcohols distilled off. The aqueous-alcoholic mixture was concentrated by repeated redistillation with anhydrous potassium carbonate, and sufficient solid calcium chloride then added to give a 40% solution. The solution was shaken with xylene for several hours, and the xylene separated and washed several times with a fresh calcium chloride solution to remove any traces of methyl and ethyl alcohols. The original calcium chloride solution was also washed several times with xylene to remove the last traces of *n*- and *iso*-propyl alcohol.

Methyl and ethyl alcohols were recovered together from the calcium chloride solution by distillation, and the distillate was dried and its density determined. The alcohols were then estimated by oxidation with (1) potassium dichromate and sulphuric acid and (2) potassium permanganate in the cold.

The *n*- and *iso*-propyl alcohol were extracted from the xylene solution with water, and dehydrated by distillation with anhydrous potassium carbonate. The density of the mixture was determined, and the alcohols subsequently estimated by oxidation with potassium dichromate and sulphuric acid.

iso*Propyl alcohol and acetone.* A portion of the condensate free from aldehyde was oxidised with potassium dichromate and sulphuric acid in the cold for 3—4 hours, and the excess chromic acid reduced by adding ferrous sulphate. The mixture was then made alkaline with potassium hydroxide and steam-distilled, and the total acetone estimated by means of hydroxylamine hydrochloride. The acetone in the original condensate was estimated by the Scott-Wilson method (*Bull. Soc. Chim. biol.*, **1932**, **14**, 885), mercurous cyanide and hydrogen peroxide being used, and the *iso*propyl alcohol found by difference.

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350. *The Oxidation of Propane. Part III. The Kinetics of the Oxidation.*

By D. M. NEWITT and L. S. THORNES.

The conditions under which the reaction of an equimolecular propane–oxygen medium has a negative temperature coefficient have been investigated, and the coefficients for the surface and homogeneous reactions measured separately.

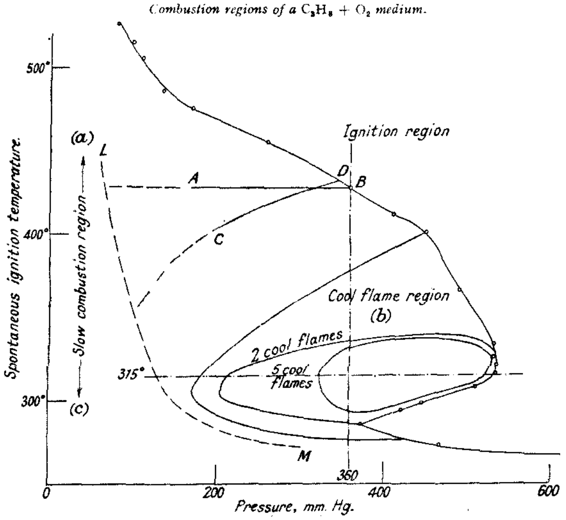
The influences of vessel diameter and of diluents on the rate of reaction are shown to be such as would result from the operation of a chain mechanism. The analytical and kinetic results as a whole suggest that the intermediate stages exerting a controlling influence on the course and rate of the combustion are: (1) an initiating process which almost certainly starts as a surface reaction and gives rise to critical concentrations of a higher aldehyde, (2) a series of homogeneous reactions by which the higher aldehyde is reduced stepwise to formaldehyde, and (3) a reaction occurring simul-

taneously with (2) and resulting in the aldehyde (or some intermediate product of its further oxidation) undergoing thermal decomposition.

THE results of numerous investigations covering a wide range of experimental conditions have shown that the oxidation of the paraffin hydrocarbons is characterised by an induction period during which a surface reaction takes place and small concentrations of certain intermediate products are built up, followed by a gas-phase reaction which has usually, though not invariably, the characteristics of a chain reaction. The homogeneous reaction of the lower members of the series, methane and ethane, has a positive temperature coefficient, and its progress may be followed by measuring the change of pressure with time in a closed system or by the rate of oxygen consumption.

FIG. 1.

Combustion regions of a $C_3H_8 + O_2$ *medium.*



On ascending the series, the phenomena associated with the homogeneous reaction become more complex and, as shown in Part I, it is necessary to distinguish four types of reaction which may conveniently be defined by reference to an ignition temperature–pressure diagram such as that shown in Fig. 1. This refers to an equimolecular propane–oxygen medium reacting in a closed silica vessel; to the right of the full-line curve is a region in which spontaneous ignition always occurs after a comparatively short induction period, and to the left are three regions in which (*a*) high-temperature slow reactions, (*b*) cool-flame reactions, and (*c*) low-temperature slow reactions, severally, take place. The cool-flame region may also be further sub-divided by a system of closed curves defining the conditions under which single and multiple cool flames are observed.

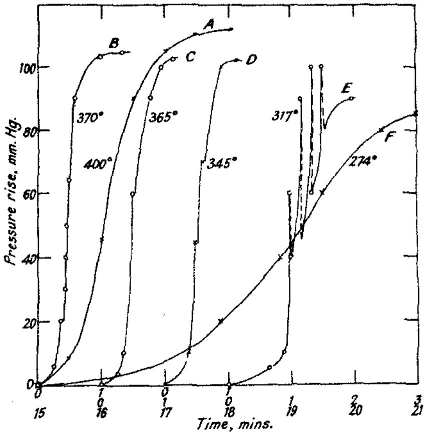
Slow combustion in the regions (*a*), (*b*), and (*c*) is characterised by certain features associated with the changes in the reactivity of the medium with temperature. For instance, if the pressure-time curves for a series of experiments along the 360-mm. isobaric lines are compared, as in Fig. 2, it will be seen that in (*a*), curve *A*, there is an induction period of

about 0·25 sec., followed by a rapid reaction during which the pressure rises uniformly to a maximum; in (*b*) the four curves *B*, *C*, *D*, and *E* show the incidence of cool flames, the number of flames increasing as the temperature is lowered; and in (*c*), curve *F*, the reaction is again normal, there being an induction period of 15 mins. followed by a slow pressure rise extending over a further 7 mins.

In curve *E*, the formation of four separate cool flames at intervals of approximately 10 secs. is clearly indicated; each flame is accompanied by a rapid rise, and its extinction is followed by an equally rapid fall in pressure, the extent of the changes being such as might well result from the variations in temperature associated with the passage of the flame. At the moment of formation of the first flame only about 10% of the oxygen present is consumed, the ratio oxygen : propane taking part in the reaction up to this point being 1·4.

FIG. 2.

Pressure-time curves of a $C_3H_8 + O_2$ *medium.*



At 345° (curve *D*) two cool flames are formed with no definite interval between them, and visual observation shows that the second flame starts before the first is quite extinguished. At 356° and 370° (curves *C* and *B*) only one flame is produced, which continues to burn until reaction is nearly complete.

It was shown in Part I that the initiation of a cool flame synchronises with the attainment of a critical concentration of higher aldehydes in the medium, the further oxidation of the aldehydes by reactions resulting in their degradation to formaldehyde being responsible for the flame propagation. The concentration of higher aldehydes at any moment is determined by their respective rates of formation and further oxidation; in the low-temperature, slow-combustion region (*c*), for example, both rates are slow and of the same order of magnitude, so that high concentrations are never reached, whilst at a somewhat higher temperature, in region (*b*), there is evidence that the rate of formation increases rather more rapidly than that of further oxidation, and critical concentrations are readily attained. The intensity of each cool flame will depend upon the concentration of the aldehydes relative to the critical concentration, and the occurrence of multiple cool flames will only be possible in a restricted zone in which a balance exists between the rates of formation and oxidation of the aldehydes. In this connection the analytical results (Part I, Table III) show that

even after the passage of a cool flame a relatively large amount of higher aldehydes still remains in the medium.

The mechanism of the oxidation of the higher aldehydes has not yet been satisfactorily elucidated, and until further experimental data are available it is not possible to identify the individual steps by which they are transformed into lower members of the series. Reference may be made, however, to experiments by Pope, Dykstra, and Edgar (*J. Amer. Chem. Soc.*, 1929, **51**, 1875, 2203) upon the oxidation of *n*-octane, in which there is evidence that octaldehyde is oxidised directly to heptaldehyde with the liberation of carbon monoxide or dioxide and water:

$$CH_3{\cdot}[CH_2]_6{\cdot}CHO + O_2 = CH_3{\cdot}[CH_2]_5{\cdot}CHO + H_2O + CO$$

and

$$CH_3{\cdot}[CH_2]_6{\cdot}CHO + 1\tfrac{1}{2}O_2 = CH_3{\cdot}[CH_2]_5{\cdot}CHO + H_2O + CO_2$$

Our experiments, on the other hand, indicate that an aldehyde peroxide and/or per-acid is an important stabilised intermediate product, and that during the passage of a cool flame two processes are operative, the one leading to the ultimate formation of formaldehyde and the other to simpler products as the result of the thermal decomposition of one or more of the intermediates taking part in the main reaction. If the oxidation of the higher aldehyde proceeds by a chain mechanism, the latter process would cause chain breaking and would satisfactorily account for an upper limit of cool flame propagation.

Evidence for a Chain Mechanism.—Egerton (*Nature*, 1928, **121**, July 7, Suppl.), Norrish (*Proc. Roy. Soc.*, *A*, 1935, **150**, 36), Ubbelohde (*ibid.*, *A*, **152**, 354), and von Elbe and Lewis (*J. Amer. Chem. Soc.*, 1937, **59**, 976) have recently summarised the evidence in favour of a chain theory of hydrocarbon combustion, and have suggested definite mechanisms by which the available kinetics and analytical data for the simpler hydrocarbons may be interpreted; the corresponding data for the higher members, however, are still incomplete, and until more is known as to the nature and identity of the intermediate products of their oxidation no direct application of any of the proposed mechanisms is possible. In the case of propane, however, the general characteristics of the slow combustion as already described, and the additional kinetic data given below, are such as would result from the operation of branching or degenerate branching chains.

The Relative Reactivities of Propane–Oxygen Media.—It will be recalled that the most reactive methane– or ethane–oxygen medium is one containing the hydrocarbon and oxygen in the ratio 2 : 1, and any excess of either reactant above these proportions gives rise to a marked retardation in both the slow and the explosive combustion (cf. Bone and Hill, *Proc. Roy. Soc.*, *A*, 1930, **129**, 434).

With the higher hydrocarbons, a satisfactory comparison can only be obtained in the high-temperature, slow-combustion region, and in such circumstances the 1 : 1 hydrocarbon–oxygen medium is found to be the most reactive. For instance, it will be seen from the pressure–time curves in Fig. 3, which refer to the reaction at 360 mm. and 408° of a series of propane–oxygen mixtures, and the inset curve showing the relation between reaction velocity ($\Delta P/\Delta t$) and hydrocarbon concentration, that the velocity of this mixture is considerably greater than that of either the 2 : 1 or the 1 : 2 mixture; a similar result is obtained when the rate of oxygen consumption is plotted against the hydrocarbon concentration. Corresponding observations have also been recorded for pentane–oxygen mixtures by Pidgeon and Egerton (J., 1932, 661).

The Influence of Diluents and of the Dimensions of the Reaction Vessel.—In a chain process in which the chains originate and/or terminate at the walls of the reaction vessel, the rate of reaction is found to depend *inter alia* upon the dimensions of the vessel and the composition of the medium, and the effect of increasing the diameter of the vessel or of adding an inert diluent will result in an increase. Since the spontaneous ignition temperature of a combustible medium is the temperature at which the reaction attains a certain critical velocity, the influence of the above factors may readily be determined by a comparison of the ignition temperature–pressure data.

The curves *A* and *B* in Fig. 4 show graphically the relation between the spontaneous ignition temperature and total pressure for the two mixtures $C_3H_8 + O_2$ and $C_3H_8 + O_2$

$+ N_2$, respectively, and the broken curve B' the data for the nitrogen-diluted mixture plotted in the basis of the partial pressure of $(C_3H_8 + O_2)$; the numerals placed opposite

FIG. 3.

Influence of hydrocarbon concentration on the rate of reaction of propane-oxygen media.

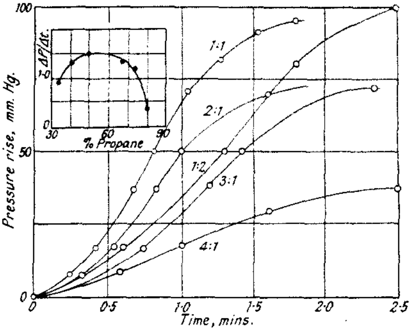
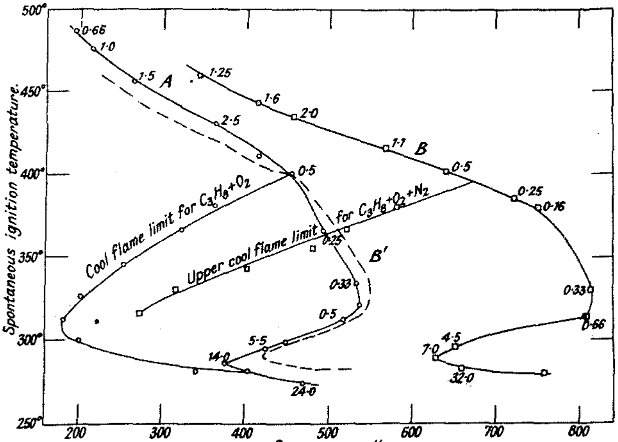


FIG. 4.

Influence of nitrogen dilution on the ignition temperature of a $C_3H_8 + O_2$ medium.



the experimental points in the curves give the induction periods in minutes before ignition occurs.

By comparing curves A and B', it will be seen that addition of nitrogen raises the lower

limit of inflammation by about 15°, increases the critical transition pressure by about 20 mm., and raises the lower cool-flame limit without appreciably altering the upper limits. In the cool-flame region between 295° and 395° it retards, and above this region it accelerates, the reaction. From the standpoint of a chain mechanism these results suggest either a relative change in the extent to which chain-breaking occurs on the walls and in the gas phase on passing from the cool-flame to the slow-combustion region, or an influence of the diluent on chains initiated at the walls.

That chain-breaking occurs predominantly at the walls may be inferred from a comparison of the critical ignition pressures of an equimolecular propane–oxygen mixture reacting in vessels of different diameters. The data in Table I for three glass vessels of

TABLE I.

Ignition pressure of a $C_3H_8 + O_2$ *medium in vessels of different diameters.*

Diameter of vessel, cm.		4·8	3·7	2·5
	Ignition temp.	Critical pressure, mm.		
Slow combustion zone	450°	590	670	800
	425	650	745	865
	400	670	790	910
Cool flame zone	375	635	735	860
	350	615	695	820
	325	625	705	825
	300	550	590	735

diameters 2·5, 3·7, and 4·8 cm., severally, show, for example, that both in the cool-flame and the slow combustion region, the pressure p at which ignition occurs is a function of the diameter of the vessel d, the product pd^n being a constant and n having a value of 0·46; and this relation has been shown, on theoretical grounds, to hold for all chain processes in which the chains are broken principally at the walls (Semenoff, "Chemical Kinetics and Chain Reactions," Oxford, 1935). Furthermore, the lower temperature limit of inflammation, which is substantially independent of pressure over a wide range, narrows as the diameter is reduced, as follows:

Diameter of vessel, cm.	4·8	3·7	2·5
Lower temperature limit of inflammation	270°	280°	285°

Attention may also be directed to the marked sensitivity of the oxidation reaction to "wall" conditions. It is found that both the duration of induction and the subsequent rate of reaction are influenced by the previous history of the vessel; and each time the vessel is cleaned it is necessary, in order to obtain reproducible results, to "sensitise" its surface by carrying out an ignition experiment in the high-temperature zone.

The Negative Temperature Coefficient.—It will be clear from an inspection of the ignition curve in Fig. 1 that, if true ignition be related to reaction velocity according to the thermal view, the variation of ignition temperature with pressure must be associated with a negative temperature coefficient of the reaction in the cool-flame and high-temperature slow-combustion regions, and that in the latter region there will be limiting conditions for which the coefficient will have a zero value.

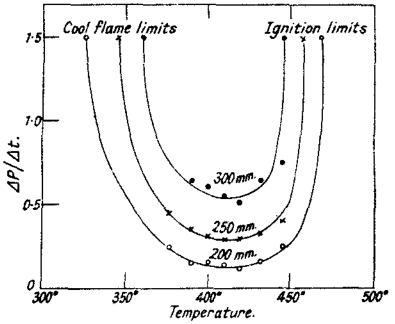
Pease (*J. Amer. Chem. Soc.*, **1929**, **51**, 1839) first directed attention to the occurrence of negative values in the oxidation of a $C_3H_8 + O_2 + 2N_2$ medium in a flow system at atmospheric pressure and 350—400°, and similar isolated observations have been made for pentane, heptane, and octane (Aivazov and Neumann, *Acta Physicochim.*, **1936**, **4**, 575; Beatty and Edgar, *J. Amer. Chem. Soc.*, **1934**, **56**, 112). The flow method, however, is not well adapted to the measurement of the temperature coefficients of reactions having comparatively long induction periods, nor does it enable a distinction to be drawn between the coefficients of the surface and the homogeneous reaction and the influence of pressure upon them. A static method similar to that described in Part I, on the other hand, allows the two reactions to be examined separately, and a wide range of conditions in respect of temperature and pressure to be employed.

The region of particular interest is that in which slow combustion takes place above the

upper limit of cool-flame propagation (see Fig. 1). Experiment shows that on progressively increasing the reaction temperature from the upper cool flame limit, the pressure being maintained constant, the rate of reaction at first diminishes, passes through a minimum at which the temperature coefficient is zero, and then increases until finally ignition takes place. The relation between pressure increase and time for reactions in this region (Curve *A*, Fig. 2) indicates that, after a short induction period, oxidation occurs uniformly, and from the slope of the pressure–time curves the rate of reaction ($\Delta P/\Delta t$) can be measured. The curves in Fig. 5 show graphically the variations in reaction rate with temperature for an

FIG. 5.

Influence of temperature on the rate of reaction of a $C_3H_8 + O_2$ *medium.*



equimolecular propane–oxygen mixture at 200, 250, and 300 mm. pressure, severally; they all terminate at low temperatures in cool-flame ignition, and at high temperatures in true ignition, their minima corresponding with a temperature of 420°. It is thus possible to indicate on Fig. 1 by means of a straight line *AB* the conditions under which the slow reaction has a zero coefficient, and a region between *AB* and the upper limit of cool-flame propagation in which the coefficient is negative. In the cool-flame region itself, reaction proceeds *per saltum* with alternate accelerations and retardations of velocity, and the influence of temperature can only be compared over restricted phases of the reaction.

The velocity of the surface reaction can be measured approximately by the duration of the induction period. With an equimolecular propane–oxygen medium at 360 mm., for example, reaction is first detectable at about 280°. At 285° the induction period is 5 mins. and on progressive increase of temperature it diminishes until at 365° it is about 5 secs., or comparable in magnitude with the time taken in filling the reaction vessel. With further increase of temperature, the induction period passes through a minimum and thereafter increases steadily until the ignition point is reached, whereat it has a value of *ca.* 30 secs. At or immediately above the ignition temperature the coefficient again changes sign and the induction period diminishes with further rise.

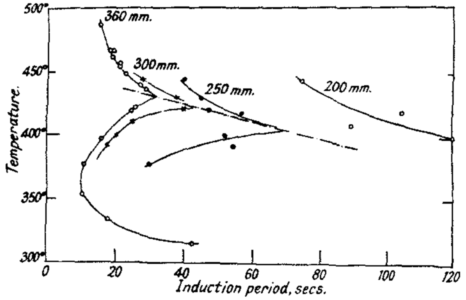
The relation between induction period and temperature for the above medium at 360, 300, 250, and 200 mm. is shown by the curves in Fig. 6; it will be seen that in the experiments at 360 and 300 mm. the minima occur at about the upper cool-flame limits.

The temperature at which the coefficient for the surface reaction becomes zero increases with pressure as shown by the line *CD* (Fig. 1), and the two loci for the homogeneous and for the gas phase reactions meet at the true ignition curve. The low-pressure extremities of these two lines would probably terminate on the curve *LM*, which marks the limits of temperature and pressure at which no discernible reaction takes place after 2·5 hours;

the triangular area enclosed by the three curves would then be one in which the temperature coefficients of the two reactions have opposite signs.

FIG. 6.

Variations of the induction periods of a $C_3H_8 + O_2$ medium with temperature.



On traversing an isothermal line in the cool-flame region, the induction period is found to diminish as the pressure is progressively raised. The data at 315° are as follows:

Pressure, mm.	515	437	382	321	194
Induction period, mins.	0·5	0·5	1·5	2·83	14·0

Discussion.

The occurrence of a negative temperature coefficient in a complex process nearly always means that the integrated effect of two or more dependent reactions is being observed; and in the present instance the analytical results are in conformity with this view. It was shown in Part I that the high-temperature, slow-combustion reaction of propane is always accompanied by intense luminescence and by the formation of comparatively high concentrations of higher aldehydes and of peroxidic substances; the latter reach a maximum at a somewhat later stage than do the former, and there is evidence that they result from the further oxidation of the aldehydes. There is, indeed, little doubt but that the kinetics of the process depends to a large extent upon the mechanism of this oxidation, and further work upon it is now in progress.

The analytical and kinetic results as a whole suggest that the factors determining the main course of the oxidation of the higher hydrocarbons are by no means as complex as is generally supposed, the number of intermediate steps which may be assumed to exert a controlling influence on the course and rate of the combustion being strictly limited.

The principal facts can be accounted for by the operation of three processes leading to the formation of stabilised intermediate products which may be recognised by chemical analysis. These are: (1) an initiation process which almost certainly starts as a surface reaction and gives rise to the formation of critical concentrations of an aldehyde having the same number of carbon atoms as the parent hydrocarbon, (2) a series of homogeneous reactions by which the higher aldehyde is reduced stepwise to formaldehyde, and (3) a reaction occurring simtaneously with (2) and resulting in the aldehyde, or some intermediate product of its further oxidation, undergoing thermal decomposition; if, as seems probable, chain mechanisms are involved in (1) and (2), this reaction would, by terminating the chains, account for the observed limits of cool-flame propagation and for the negative temperature coefficient. Furthermore, any of the recently suggested chain mechanisms based upon the formation and interaction of radicals would, on certain reasonable assumptions, give rise to the above sequence of changes.

IMPERIAL COLLEGE, LONDON, S.W. 7. [*Received, July 21st, 1937.*]

351. *The Electrolytic Separation Factor of Deuterium at Very Low Concentrations.*

By H. F. Walton and J. H. Wolfenden.

An attempt has been made to reproduce the results of Applebey and Ogden, who obtained isotopic separation factors between 30 and 100 in electrolysing water containing about twice the deuterium content of tap-water under conditions likely to minimise secondary isotopic exchange. Their observations, if confirmed, would be of great theoretical interest, since they suggest the possibility that quantum-mechanical " tunnelling " may play a part in the electrolytic separation. The cells used in the present investigation were similar in principle to, though not identical in design with, those used by Applebey and Ogden. Completely distilled tap-water was used in making up the electrolyte; the evaporation loss during electrolysis was measured and corrected for. The separation factors obtained were not abnormally great, lying between 6·5 and 8, and were not significantly different from those obtained at higher deuterium concentrations with the same cells.

This work was undertaken in an attempt to repeat some striking results by Applebey and Ogden (J., 1936, 163), who obtained electrolytic separation factors between 30 and 100 at a nickel cathode by reducing to a minimum the amount of secondary isotopic exchange between cathode gas and electrolyte. The latter object was achieved by working with water of low deuterium concentration (approximately twice that of tap-water) and by designing the cell so that the circulation of electrolyte ensured very rapid removal of the evolved gas from the cathode. Applebey and Ogden's results, if authentic, are of great potential theoretical significance, because such a high separation factor could scarcely be explained except as a result of quantum-mechanical " tunnelling " of protons and deuterons through an energy barrier. We have therefore attempted to reproduce their results.

The cells used in our investigation were similar in principle to those of Applebey and Ogden. Six cells were run in series with a water voltameter which enabled us to estimate and correct for the evaporation loss during electrolysis. The electrolyte was completely distilled tap-water containing 2·5% of sodium hydroxide; this was reduced to one-fifth of its bulk by electrolysis, neutralised with carbon dioxide, and normalised with respect to the oxygen isotopes by sulphur dioxide; the density of the final product was determined by flotation temperature.

The separation factors obtained were not abnormally great, nor were they significantly higher than those obtained at higher deuterium concentrations with the same cells. They averaged about 8, Gabbard and Dole's value (*J. Amer. Chem. Soc.*, 1937, **59**, 181) of 1/6,900 being taken for the abundance of deuterium in natural water. Measurements with the same cells at a higher deuterium concentration gave values of about 6; if a slightly higher value for the abundance of deuterium is assumed, this small difference between the two sets of values vanishes.

Experimental.

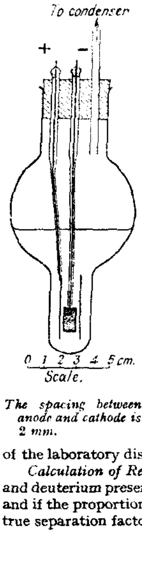
The Electrolytic Cells.—The arrangement of electrodes used was not the same as the " grid " form (I) which Applebey and Ogden used for low deuterium concentrations and with which the high separation factors were observed, but resembles the form (II) used by them at high deuterium concentrations. The latter type was chosen rather than the former because it is much more convenient for weighing and for control of the evaporation loss. Applebey and Ogden obtained separation factors with cell II with 3·7% D_2O which were *higher* than those obtained with cell I and 1·8% D_2O; since they found that in both types of cell the separation factor fell with rising deuterium concentration, there seems no reason to believe that cell I is likely to give separation factors higher than cell II.

In our cells, illustrated in the figure, the electrodes were made of nickel rods and tube, welded to nickel leads and mounted concentrically. The inner rod served as cathode, the outer tube as anode. The main difference between this arrangement and that of Applebey and Ogden (cell II) is that here the outer cylinder is prolonged upwards to give a higher column of gas-loaded electrolyte and hence more powerful circulation.

The cells were cooled to between 14° and 16° by placing them in a tank through which water circulated. Evaporation loss was further reduced by fitting the cells with condensers. The evaporation loss corresponded to a saturation temperature for the evolved gases of 11—12°. The water voltameter, which permitted the measurement of this loss, was fitted with nickel electrodes and contained 8% sodium hydroxide as electrolyte; its outlet carried drying-tubes of calcium chloride and phosphoric oxide. The difference between the loss in weight of this cell and the loss in weight of the electrolysis cells in series with it gives the amount of evaporation in the latter.

Procedure in Electrolysis, and Purification of Product.—150 C.c. of the electrolyte, which was made up from completely distilled tap-water, were pipetted into each cell; the cells were then corked and weighed. Electrolysis was carried on at 0·8 amp./cm.^{2} until the cells had lost about 120 g. in weight.

The electrolyte was first neutralised by bubbling carbon dioxide through it. After distillation, a stream of sulphur dioxide, from a siphon and dried over phosphoric oxide, was bubbled for 3 hours through the distillate cooled in a water tank. The sulphur dioxide was removed by first passing air through the liquid for 3 hours and then distilling it in a vacuum. A third and final distillation was carried out after adding a few crystals of potassium permanganate and a little sodium carbonate. All distillations were carried out in a vacuum in H-shaped tubes with one limb cooled in ice and the other heated in warm water. In this way it is possible to achieve complete distillation without splash.



The spacing between anode and cathode is 2 mm.

The possibility of isotopic displacement caused by evaporation during the gas bubbling was excluded by the following blank experiment: 7·9 g. of water, whose density exceeded that of natural water by 42 parts per million, were treated with 2·0 g. of sodium hydroxide (containing 2% of water). The solution was subjected to the complete procedure of purification; the density excess of the product, after allowance for the addition of the sodium hydroxide, should be 39·5 parts per million. It was found to be 39 parts per million.

Density Determination.—A few c.c. of the sample were placed in a Monax test-tube with a calibrated glass float about 2 c.c. in volume. Air was blown through for ½ hour to saturate the water, since air-saturated water is 4—5 parts per million less dense than air-free water at 13°, the temperature of the measurements. The temperature at which the float just rose from the bottom on cooling was noted. With slow cooling (<0·01°/min.) this temperature could be reproduced to ± 0·005°, corresponding to a density interval of 0·5 part per million.

The float was calibrated with magnesium sulphate solutions of known density, and a normal water standard prepared from a sample of the original electrolyte by submitting it to the same purification treatment as the solutions after electrolysis. Its density was within 1 part per million of the laboratory distilled water used in making up the standard magnesium sulphate solutions.

Calculation of Results.—(i) *The evaporation correction.* If the numbers of atoms of protium and deuterium present before and after electrolysis are denoted by H_1, D_1 and H_2, D_2 respectively, and if the proportion of water lost by evaporation to that lost by electrolysis is called k, then the true separation factor is

$$\alpha = \frac{(1 + k) \ln H_1/H_2 - k \ln(H_1 + D_1)/(H_2 + D_2)}{(1 + k) \ln D_1/D_2 - k \ln(H_1 + D_1)/(H_2 + D_2)}$$

which for small deuterium concentrations simplifies to

$$\alpha = \frac{\ln H_1/H_2}{\ln D_1/D_2 - k(\ln H_1/H_2 - \ln D_1/D_2)}$$

These expressions assume that, during the electrolysis, k is constant and that there is no isotopic discrimination in evaporation.

(ii) *The evaluation of deuterium concentration from the density.* The specific gravity of pure deuterium oxide at the flotation temperature is 1·1073 (Lewis and Macdonald, *J. Amer. Chem. Soc.*, 1933, **55**, 3057; Selwood, Taylor, Hipple and Bleakney, *ibid.*, 1935, **57**, 642). The mole-fraction of deuterium, N_2, is deduced from the expression (cf. Luten, *Physical Rev.*, 1934, **45**, 161): density $= 1 + N_2(0{\cdot}1073 - 0{\cdot}0012N_1)$. To the value of N_2 thus obtained must be added

the mole-fraction of deuterium present in natural water. Gabbard and Dole's value (*loc. cit.*) for this is 0·000145.

(iii) *Sources of error.* The principal errors are in the density determinations and may be summarised as follows:

	Effect on density (p.p.m.).
Uncertainty in float calibration	1
Uncertainty in flotation temp.	½—1
Total	1½—2

Such an error in the density might affect the separation factor by 15%. The errors in weighing would not affect the separation factor by more than ½%. A final source of error arises from the slight isotopic separation caused by the evaporation during electrolysis; this makes the observed separation factor too great by an amount unlikely to exceed 3%. The probable limits between which the separation factors lie are given in the table of results.

The following tables contain the results obtained in electrolysing natural water and water containing 0·245% deuterium respectively.

Electrolysis of natural water.

Initial electrolyte: 2·32% sodium hydroxide in completely distilled tap-water. Amount placed in each cell: 153·15 g.; H_2O before electrolysis (moles): 8·346; D_2O before electrolysis (mole): 0·00121; *proportion of D before electrolysis* (p.p.m.): *145; amount electrolysed (from voltameter weighings)*: 115·84 g.

Cell No.	2.	3.	4.	5.	6.
Δd of solution after electrolysis (p.p.m.)	40·5	40·5	42·5	42·0	42·5
Proportion of D after electrolysis (p.p.m.) ...	525	525	545	540	545
H_2O after electrolysis (moles)	1·786	1·787	1·783	1·785	1·772
D_2O after electrolysis (moles $\times 10^{-6}$)	938	938	971	960	966
k (evapn. const.)	0·0200	0·0198	0·0203	0·0200	0·0220
Separation factor	$6{\cdot}7_5$	6·7	8·0	$7{\cdot}5_5$	$7{\cdot}9_5$
Probable limits of separation factor	5·8	5·8	7·0	$6{\cdot}7_5$	6·6
	8·3	$8{\cdot}2_5$	9·4	8·8	$9{\cdot}9_5$

The effect of assuming a different value for the abundance of deuterium in natural water may be judged from the fact that the separation factor for cell 2, for example, becomes $4{\cdot}7_5$ if the proportion of deuterium before electrolysis is taken as 166 p.p.m. instead of 145.

Electrolysis at a higher deuterium concentration.

Initial electrolyte: 2·07% sodium hydroxide in 0·2445% heavy water. Amount placed in each cell: *ca.* 122 g.; proportion of D before electrolysis (p.p.m.): 2445; amount electrolysed (from voltameter weighings): 88·40 g.

Cell No.	3.	5.	6.
H_2O before electrolysis (moles)	6·673	6·669	6·674
D_2O before electrolysis (mole)	*0·01637*	*0·01637*	*0·01637*
Δd after electrolysis (p.p.m.)	783	794	802
Proportion of D after electrolysis (p.p.m.)	7350	7630	7705
H_2O after electrolysis (moles)	1·673	1·676	1·682
D_2O after electrolysis (mole)	0·01271	0·01290	0·01304
k (evapn. const.)	0·0191	0·0178	0·0175
Separation factor (±5%)	6·0	6·3	$6{\cdot}6_5$

Dr. Ogden kindly came to Oxford in a joint effort to discover a reason for the discrepancy between our results and those obtained by Mr. Applebey and himself. The only difference in experimental conditions which he regarded as conceivably significant was the greater opportunity for contact with the anode which was afforded to the cathode gas in our cells. On general grounds, and in view of other experiments of ours (to be published later) which show that the separation factors at nickel cathodes with rigid exclusion of oxygen and grease and no opportunity for contact of cathode gases with the anode are substantially the same as those obtained under the crudest conditions of technical electrolysis, we incline to the view that this difference in cell design cannot account for the conflict between the two sets of results. It is noteworthy that the evaporation correction which we applied would tend to produce separation factors *higher* rather than lower than those of Applebey and Ogden.

We thank Mr. Applebey and Dr. Ogden for the opportunity for helpful discussion which they gave us. One of us (H. F. W.) is indebted to the Department of Scientific and Industrial Research for a maintenance grant.

Physical Chemistry Laboratory, Balliol College and Trinity College, Oxford. [*Received, August 9th*, 1937.]

352. *The Photo-expansion of Bromine.*

By William Smith, Mowbray Ritchie, and E. B. Ludlam.

Investigation has been made of the photo-expansion of bromine. An equation has been developed, in which the relationship between the photo-expansion, the thermal conductivity, the total pressure, and the light absorbed is shown.

The effect on the photo-expansion of bromine of adding various foreign gases has been examined. The addition of such gases, in general, increases the photo-expansion by facilitating the homogeneous recombination of bromine atoms. The series representing the efficiencies of the triple collision process is given by $CO_2 > O_2 > N_2 > H_2 > A$.

The variation of the thermal conductivity with the pressure of bromine has been examined.

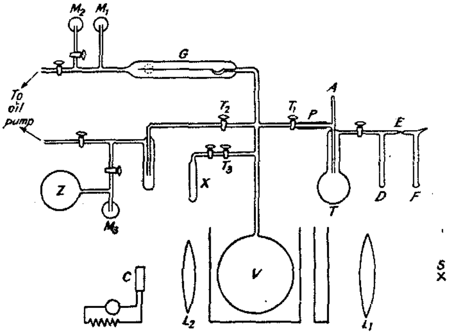
Addition of water vapour after very careful drying did not produce any marked effect in the expansion.

The present work was undertaken with the object of studying the effect of foreign gases on the expansion of bromine when exposed to light. It was hoped to draw definite conclusions as to the part played by dissociation of the bromine into atoms, the diffusion of these to the walls, their recombination in the gas phase and on the walls of the vessel, and finally to clear up what may be called the mystery of the contradictions which exist as to the effect of moisture and of careful drying on the magnitude of the expansion.

Since this work was begun papers have been published by Rabinowitch and his co-workers which have added considerably to the quantitative knowledge of the dissociation and recombination. Their experimental method was quite different from ours, depending on the photo-electric cell measurement of the decrease in the absorption of the molecular bromine when a portion had been converted into atoms, whereas we were concerned to explore the effect of inert gases by measuring direct expansion which would enable more direct comparison to be made with earlier work.

Apparatus.—The apparatus used is shown diagrammatically in Fig. 1. The spherical insolation vessel V, made of soft glass, had an internal volume of 1500 c.c. and was connected to the

Fig. 1.



Bourdon gauge as shown. The vessel was immersed in water contained in a bath which had plane glass walls. (The temperature of the water was that of the room, which did not vary by more than 1° in the course of a day.)

The gauge G had a sensitivity such that 1 division of eyepiece scale = 0·210 mm. mercury. D was the bromine reservoir and Z a reservoir for inert gases, M_3 being a mercury manometer used to give an indication of the amount of gas in Z.

P was a tube about 4 cm. in diameter, loosely filled with pure phosphoric oxide. This was used to ensure that the moisture content of the bromine was at a minimum. As fairly high pressures were used, the taps were lubricated with apiezon grease which had been exposed for several days to bromine vapour.

The light source S was a 500 watt projector lamp. As shown by a voltmeter, the lamp was run at 220 volts from a 230 volts A.C. mains by hand-controlled resistance. By means of a condenser lens L_1, a convergent beam of light was made to fall upon the insolation vessel. Since the latter was spherical, a convergent beam seemed preferable to a parallel beam. Before entering the vessel, the light was passed through a 14 cm. layer of a 2% solution of copper sulphate. The emerging beam of light was focused upon a Weston Photronic cell C, by means of a condenser lens L_2. The cell, shielded from external radiations, was connected in series with a Weston galvanometer and a fixed resistance. This system always gave perfectly reproducible results.

Preparation of Materials.—Bromine, bought as pure, had the last traces of chlorine removed by distillation from a solution of potassium bromide. Any traces of hydrobromic acid were removed by shaking the bromine with a very dilute solution of potassium hydroxide, separating it, and finally distilling it from moist zinc oxide. It was kept over phosphoric oxide. Before use, it was fractionally distilled at low pressure several times. This was done by cooling F in carbon dioxide–acetone, and cooling the receiving tube D in liquid air. The initial and the final fraction were in each case removed by pumping off. The final sample was collected in D, and the constriction at E sealed.

Before being collected in the reservoir, argon (99·5%), nitrogen (99%), oxygen (97%), carbon dioxide, all supplied in cylinders by the British Oxygen Company, sulphur dioxide (from a siphon), and air were bubbled slowly (2 bubbles per second) through two wash-bottles containing concentrated sulphuric acid and then passed through a tube, about 20 cm. long, loosely packed with phosphoric oxide. Before use, argon, nitrogen, oxygen and air were passed through a liquid air trap.

Experimental Procedure.—The apparatus was evacuated by a Hyvac oil-pump, and the transmitted light intensity I_0 at zero pressure of bromine measured by means of the photronic cell system. The levels of the mercury columns in the manometers and the initial position of the gauge pointer image were observed. After " washing " out with bromine vapour, bromine was introduced into the insolation vessel by way of tap T_1 to the desired pressure and illuminated under standard conditions; the deflections of the gauge pointer and galvanometer needle were observed, giving the photo-expansion and transmitted light intensity I at the pressure $[Br_2]$. This process was repeated several times, no appreciable deviations being observed.

In examining the effect of " foreign " gases, the pressures of bromine used were in general 30, 40, and 50 mm. The photo-expansion and the light energy absorbed ($I_{abs.} = I_0 - I$) for the particular pressure having been recorded, the " foreign " gas was added to the required pressure; the transmitted light intensity was then redetermined, and the photo-expansion measured. Before the latter measurement was made, the bromine–gas mixture was allowed 15 minutes to attain complete mixing; this was found to be necessary, as otherwise incorrect results were obtained.

Theoretical Discussion of the Experiment.

Studies of the photo-dissociation of bromine molecules and of the recombination of bromine atoms have shown that recombination to form the homopolar molecule requires what is virtually a triple collision between the two atoms and a third body acting as a stabiliser (Born and Franck, *Z. Physik*, 1925, **31**, 411; Jost and Jung, *Z. physikal. Chem.*, 1929, **3**, *B*, 83). The probability of recombination by an immediate reversal of the primary photo-chemical process with emission of radiation has been shown to be small under the conditions of the photo-chemical experiments (cf. Kondratjew and Leipunsky, *J. Phys. Chem.*, *U.S.S.R.*, 1932, **3**, 383).

The concentration of atoms in the gas phase may be considerably reduced by removal of atoms by the walls of the reaction vessel. This effect will be minimised by high pressures of the reactants; the same result will be produced by the addition of an inert gas, but at the same time removal of the atoms by the gas-phase triple collision process will be facilitated, the added gas acting as the third body (Jost and Jung, *loc. cit.*; Jost, *ibid.*, 1929, **3**, *B*, 95; Ritchie, *Proc. Roy. Soc.*, 1934, *A*, **146**, 828). Absolute velocity coefficients for the triple collision processes with different third bodies have been given by, *inter alios*, Hilferding

and Steiner (*Z. physikal. Chem.*, **1935**, *B*, **30**, 399) and Rabinowitch (*Trans. Faraday Soc.*, 1937, **33**, 283).

The above considerations refer to bromine atoms obtained by photo-dissociation by light of wave-lengths in the continuous region of the bromine spectrum. Jost (*loc. cit.*) found that the velocity of hydrogen bromide formation in the band region about 5650 A. was approximately the same as in the continuum, indicating the dissociation by collision of such primarily excited molecules into normal atoms, little distinction being observed between normal and excited atoms in the photo-synthesis.

The bromine atoms produced by the absorption of light may thus be considered in two divisions : (a) those recombining in the gas phase by triple collision, the heat of combination appearing in the gas phase and causing an increase of pressure ; (b) those removed by surface action. The above effects may then be represented by the following scheme :

No.	Reaction.	Velocity coefficient.
1	$Br_2 + h\nu = Br + Br$	k_1
2	$Br + Br + M = Br_2 + M$	k_M
3	$Br + wall = \frac{1}{2}Br_2$	S

where M is an added inert gas molecule; S[Br] represents the rate at which atoms are removed from the gas phase at the wall, and includes the rate of diffusion to the wall through the gas mixture, as well as a collision factor depending on the nature of the wall itself.

If the vessel is large and the pressure high, recombination according to mechanism No. 2 will be predominant. The total heat appearing in the gas-phase will be equivalent to the energy absorbed ($I_{abs.}$) and will be independent of the gases present (except in so far as I_{abs} alters with the addition of foreign gases). In the steady state, however, the temperature rise will depend on the rate at which heat is conducted to the thermostated walls of the vessel, *i.e.*, on the thermal conductivity of the gas mixture.

In the photo-stationary state,

$$d[Br]/dt = k_1 I_{abs.} - k_M[Br]^2[M] - S[Br] = 0 \quad . \quad . \quad . \quad . \quad . \quad (1)$$

On the assumption that the rise in temperature indicated by the increase in pressure Δp is due entirely to heat produced in the gas and that heat produced on the surface does not affect Δp, the heat produced in the gas phase is proportional to $k_M[Br]^2[M]$. In the steady state, the heat transferred to the walls per second will be equal to the heat produced in the gas phase per second, and the rise in temperature will depend on the thermal conductivity of the gas mixture.

In the case of a gas, the thermal conductivity is independent of the pressure when the pressure is sufficiently high (see later experiments; p. 1687). In the present experiments, with a relatively narrow beam, fixed in position, traversing the gas mixture with the walls at a fixed temperature (thermostated), we may apply the general conductivity formula, $Q = K . A . \Delta T/x$ (where Q is the heat quantity transferred per second across an area A, ΔT is the difference in temperature between two planes at a distance x, and K is the thermal conductivity coefficient of the medium between the two planes), in the approximate form $Q \propto \Delta T . K$, where ΔT represents the rise in temperature of the mixture in the illuminated steady state. Since for any gas mixture the increase in pressure is proportional to the rise in temperature, $Q \propto \Delta p . K$. Hence

$$K\Delta p \propto k_M[Br]^2[M], \text{ or } RK\Delta p = k_M[Br]^2[M]$$

where R is a constant.

From equation 1, $[Br] = (-S \pm \sqrt{S^2 + 4k_1 I_{abs.} k_M[M]})/2[M]k_M$.

k_1 may be taken as 2, and since [Br] must be positive,

$$[Br] = (-S + \sqrt{S^2 + 8I_{abs.}k_M[M]})/2[M]k_M.$$

But
$$RK\Delta p = k_M[M][Br]^2 = 2I_{abs.} - S[Br].$$

Hence, on substituting for [Br],

$$RK\Delta p = 2I_{abs.} - S(\sqrt{S^2 + 8I_{abs.}k_M[M]} - S)/2k_M[M] \quad . \quad . \quad . \quad . \quad (2)$$

For mixtures of bromine and one inert gas, $[M]k_M$ must be replaced by $([Br_2]k_{Br_2} + [X]k_X)$, where [X] is the pressure of inert gas. Equation 2 then becomes

$$RK\Delta p = 2I_{abs.} - S(\sqrt{S^2 + 8I_{abs.}([Br_2]k_{Br_2} + [X]k_X)} - S)/2([Br_2]k_{Br_2} + [X]k_X)$$

or
$$RK\Delta p = 2I_{abs.} - Y \quad . \quad . \quad . \quad (3)$$

whence
$$I_{abs.} = \tfrac{1}{2}(RK\Delta p + Y) \quad . \quad . \quad . \quad (4)$$

The thermal conductivity K will differ for each gas mixture. Calculation of S for the various conditions was approached as follows. If t is the time taken for a bromine atom to diffuse a given distance through bromine vapour, $t \propto 1/D_{Br_2}$, where D_{Br_2} represents the diffusion factor. For a mixture of gases, we may take (Ludlam and Melville, *Proc. Roy. Soc.*, 1931, *A*, **132**, 108; Ritchie, *loc. cit.*)

$$t \propto 1/D_1 + 1/D_2 + 1/D_3 + \ . \ . \ .$$

and since
$$S \propto 1/t,$$

$$S = m(1/D_1 + 1/D_2 + 1/D_3 + \ . \ . \ . \ )^{-1}$$

where m is a constant depending on vessel dimensions, nature of the wall, etc., and

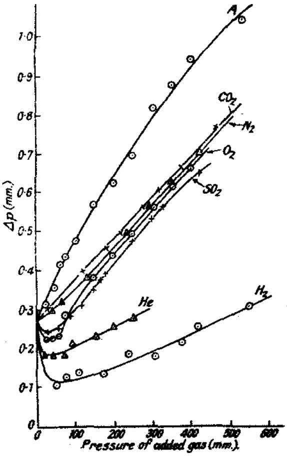
$$D \propto 1/[X]\sigma_{AX}^2(1/M_A + 1/M_X)^{-\frac{1}{2}}$$

Here M_A is the molecular weight of the particle diffusing, *i.e.*, the bromine atom, M_X is the molecular weight of the inert gas, [X] is the pressure of inert gas, and σ_{AX} is the sum of the radii of inert gas molecule and atom.

In the above general discussion, no reference has been made to the possible increase in pressure due to the dissociation itself. If the light quantum absorbed is just sufficient to dissociate the molecule into a normal and an excited atom (light of wave-length corresponding to the convergence limit), then the kinetic energy of the resultant atoms will be the same as that of the original molecule and any change in pressure on dissociation will be due to the energy of excitation of the excited atom transferred in collision. This effect will be smaller if the wave-length employed is greater than that of the convergence limit, in which case dissociation will occur only after collision of the excited molecule with other gas molecules. If the quantum be of greater energy than that required for dissociation, the excess energy will appear as kinetic energy of the products, with a consequent increase in temperature. Consideration, however, of the absolute light intensity of the source used indicated that these factors could be of small importance only and showed that the observed pressure increase was due almost entirely to the heat liberated in the atomic recombination.

Possible convection effects have also been neglected for the same reason.

FIG. 2.



Results and Discussion.

Experimental results and calculations are given in Tables I—VI. In Fig. 2, Δp is plotted against the pressure of added gas. At low pressures there may be no increase but a decrease in Δp, shown most clearly in the cases of hydrogen and helium, an effect which is to be predicted on thermal conductivity grounds alone. The first addition of inert gas will

have little effect on the number of atoms combining, but the observed Δp will depend on the thermal conductivity of the gas mixture. If this increases rapidly in the initial stages from a low value to a high one, as it does markedly in the cases of hydrogen and helium, then Δp will be relatively smaller and may fall below the original value. This decrease is more noticeable with lower pressures of bromine, since the increase in conductivity on addition of an inert gas will be greater than in the case where the pressure is initially higher.

Further addition of inert gas causes K to tend to a constant value, namely, that for the inert gas alone. At the same time, however, diffusion to the walls is prevented and the number of triple collisions increases, the latter effects outweighing the former and an increase in the photo-expansion being observed.

At high pressures of inert gas K and $I_{abs.}$ are roughly constant and S becomes small. Hence, since $[Br_2]k_{Br_2}$ is small compared with $[X]k_X$, equation 3 becomes

$$\begin{aligned} RK\Delta p &= 2I_{abs.} - S\sqrt{8I_{abs.}([Br_2]k_{Br_2} + [X]k_X)}/2([Br_2]k_{Br_2} + [X]k_X) \\ &= 2I_{abs.} - S\sqrt{2}\sqrt{I_{abs.}}/\sqrt{[X]k_X} \end{aligned}$$

But $S \propto 1/[X]$, and therefore plotting Δp against $1/[X]\sqrt{[X]}$ gives a straight line (Fig 3).

At very high pressures of added gas $RK\Delta p = 2I_{abs.}$, *i.e.*, $2I_{abs.}/\Delta p$ tends to the constant value RK as shown for nitrogen and argon in Fig. 4, where $2I_{abs.}/\Delta p$ is plotted against the pressure of added gas. The ratio of the limit values for nitrogen and argon is approximately $55/38 = 1{\cdot}44$, in agreement with the ratio of the respective thermal conductivities $2{\cdot}28/1{\cdot}58 = 1{\cdot}45$ (neglecting the relatively small pressures of bromine present).

FIG. 3.

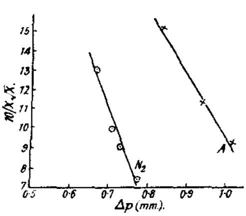
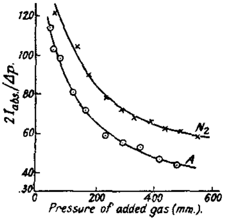


FIG. 4.



By extrapolation, curves such as those of Fig. 4 give the value of R for the experimental conditions. At zero pressure of added gas, on the other hand, the R term becomes small and the value of m in the S factor important; by taking k_{Br_2} as unity, the value of m may be estimated. The intermediate pressures then give the appropriate values of k_M in relation to k_{Br_2}.

In the calculations of Tables I—VI use was made of the following constants :—$\sigma_{Br} = 2{\cdot}0 \times 10^{-8}$ cm., $\sigma_{Br_2} = 3{\cdot}4 \times 10^{-8}$ cm., $\sigma_A = 2{\cdot}86 \times 10^{-8}$ cm., $\sigma_{N_2} = 3{\cdot}10 \times 10^{-8}$ cm., $\sigma_{O_2} = 2{\cdot}90 \times 10^{-8}$ cm., $\sigma_{H_2} = 2{\cdot}30 \times 10^{-8}$ cm., $\sigma_{CO_2} = 3{\cdot}20 \times 10^{-8}$ cm.; $k_{Br_2} = 1{\cdot}0$, $k_A = 0{\cdot}50$, $k_{N_2} = 0{\cdot}80$, $k_{O_2} = 0{\cdot}90$, $k_{H_2} = 0{\cdot}60$, $k_{CO_2} = 0{\cdot}90$; $K_{Br_2} = 0{\cdot}44$, $K_A = 1{\cdot}58$, $K_{N_2} = 2{\cdot}28$, $K_{O_2} = 2{\cdot}33$, $K_{H_2} = 15{\cdot}9$, $K_{CO_2} = 1{\cdot}37$. The thermal conductivities of the various gas mixtures were taken to be linear functions of the composition; these and values of m and R are given in the Tables. In the final columns are given the ratios of the values of the right hand side to those of the left hand side of equation 4. In any one series, the incident light intensity remained constant, though $I_{abs.}$ increased with the pressure of added gas (see Tables), corresponding to the broadening of the bromine absorption bands by the added gas molecule (cf. Ribaud, *Ann. Phys.*, 1919, **12**, 208) and due to the perturbation of the molecular forces with consequent absorption over a wider range of frequencies. This effect is particularly noticeable with hydrogen.

The ratios in the final columns of the Tables approximate to unity, indicating that the general equation satisfactorily expresses the experimental data. The values of m and R are sensibly constant for Tables I—V. On the other hand, results for carbon dioxide (Table VI) and sulphur dioxide cannot be so expressed over the entire range of pressures; application of the equation with similar values of m and R gives apparently negative values for

TABLE I.

Inert gas effect of nitrogen. $[Br_2] = 50{\cdot}0$ mm., $R = 24{\cdot}0$, $m = 5{\cdot}0 \times 10^{-11}$.

$[N_2]$, mm.	Δp, mm.	$I_{abs.}$, divs.	$RK\Delta p$.	Y.	$\frac{1}{2}(RK\Delta p + Y)$.	$\frac{R.H.S.}{L.H.S.}$
0·0	0·336	21·7	3·54	41·1	22·3	1·02
64·2	0·357	21·9	12·54	33·8	23·2	1·05
136·4	0·420	22·0	17·95	25·4	21·7	0·99
170·7	0·483	22·1	21·2	21·9	21·55	0·98
235·0	0·567	22·2	26·7	17·45	22·1	1·00
284·6	0·609	22·3	29·2	14·75	22·0	0·99
336·5	0·651	22·3	31·9	12·5	22·2	1·00
390·6	0·672	22·4	34·5	10·7	22·6	1·01
441·7	0·714	22·4	35·9	9·4	22·6	1·01
494·1	0·735	22·5	38·8	8·8	23·1	1·02
567·4	0·777	22·5	39·8	8·0	22·9	1·02

TABLE II.

Inert gas effect of nitrogen. $[Br_2] = 40{\cdot}0$ mm., $R = 24{\cdot}0$, $m = 3{\cdot}5 \times 10^{-11}$.

0·0	0·273	19·9	2·9	37·6	20·25	1·02
15·4	0·273	19·9	6·25	36·1	21·2	1·06
41·0	0·294	20·0	9·7	32·9	21·3	1·06
72·7	0·336	20·1	12·9	29·7	21·3	1·06
132·9	0·378	20·5	16·1	22·2	19·15	0·93
187·4	0·462	20·5	21·7	17·3	19·5	0·95
240·0	0·504	20·6	24·3	13·1	18·7	0·92
292·0	0·567	20·9	27·8	12·1	19·95	0·97
348·2	0·630	20·9	31·7	9·7	20·7	0·99
424·7	0·714	20·9	36·2	7·8	22·0	1·05

TABLE III.

Inert gas effect of argon. $[Br_2] = 40{\cdot}0$ mm., $R = 24{\cdot}0$, $m = 3{\cdot}5 \times 10^{-11}$.

[A], mm.						
0·0	0·273	19·9	2·9	37·6	20·25	1·02
10·6	0·294	20·0	4·8	36·3	20·55	1·02
24·7	0·315	20·0	6·6	35·5	21·05	1·05
39·0	0·357	20·1	8·55	33·8	21·2	1·05
60·2	0·420	20·1	11·35	31·2	21·3	1·06
72·9	0·441	20·2	12·3	30·0	21·15	1·04
101·4	0·483	20·3	14·6	26·5	20·55	1·02
151·8	0·567	20·3	17·6	24·6	21·1	1·04
204·0	0·630	20·6	21·05	17·2	19·1	0·93
253·4	0·756	20·8	25·7	17·45	20·1	0·96
302·1	0·819	20·9	28·5	12·15	20·3	0·96
354·2	0·882	21·0	30·7	10·4	20·55	0·98
401·6	0·945	21·0	33·6	9·05	21·3	1·01
538·5	1·05	21·0	37·8	6·35	22·1	1·05

TABLE IV.

Inert gas effect of oxygen. $[Br_2] = 40{\cdot}0$ mm., $R = 24{\cdot}0$, $m = 3{\cdot}5 \times 10^{-11}$.

$[O_2]$, mm.						
0·0	0·273	19·5	2·9	37·3	20·1	1·03
79·9	0·315	20·0	12·8	27·0	19·9	1·00
100·0	0·336	20·0	14·4	25·0	19·7	0·98
149·9	0·378	20·1	17·5	18·8	18·15	0·90
202·5	0·441	20·2	21·3	15·0	18·15	0·90
253·1	0·504	20·2	25·2	12·2	18·7	0·93
301·0	0·567	20·2	28·7	10·1	19·4	0·97
352·0	0·630	20·3	32·4	8·6	20·5	1·01
400·0	0·672	20·3	34·9	7·55	21·2	1·04

TABLE V.

Inert gas effect of hydrogen. $[Br_2] = 40·0$ mm., temp. $= 25·0°$, $R = 8·0$, $m = 4·0 \times 10^{-11}$.

$[H_2]$, mm.						
0·0	0·320	24·4	1·15	47·0	24·1	0·99
24·0	0·128	25·1	3·84	46·6	25·2	1·00
48·0	0·102	25·5	4·8	45·3	25·0	0·98
74·7	0·128	25·8	7·7	44·2	26·0	1·01
109·1	0·141	26·0	10·2	42·5	26·3	1·01
171·5	0·141	26·1	12·3	38·4	24·7	0·95
241·0	0·192	26·5	18·3	34·6	26·5	1·00
313	0·179	26·7	18·5	30·8	24·7	0·93
374	0·218	26·5	23·4	27·3	25·4	0·96
421	0·256	26·4	28·2	25·2	26·7	1·01
482	0·269	26·4	30·3	23·0	26·6	1·01
570	0·320	26·4	36·8	20·1	28·4	1·07

TABLE VI.

Inert gas effect of carbon dioxide. $[Br_2] = 40·4$ mm., $k_{CO_2} = 0·90$, $R = 30·0$, $m = 8·0 \times 10^{-11}$.

CO_2, mm.						
0·0	0·273	19·1	6·55	35·3	20·9	1·09
28·1	0·294	19·1	7·22	36·8	22·0	1·15
44·0	0·336	19·2	9·37	35·8	22·6	1·18
73·6	0·315	19·5	9·8	34·4	22·1	1·13
123·4	0·399	19·7	13·5	30·2	21·8	1·11
173·7	0·399	19·8	14·3	25·5	19·9	1·01
223·1	0·504	19·9	18·6	21·6	20·1	1·01
275·2	0·567	20·0	21·25	18·3	19·8	0·99
327·6	0·609	20·1	23·15	15·6	19·4	0·97
370·3	0·672	20·1	25·75	13·8	19·8	0·98
424·0	0·714	20·2	27·6	11·9	19·8	0·98
467·3	0·777	20·2	30·2	10·7	20·45	1·01
513·4	0·798	20·2	31·2	9·6	20·4	1·01

k_{CO_2} and k_{SO_2}, the divergence being such as to indicate removal of bromine atoms by a process which does not give an appreciable heat evolution. This may be chemical reaction in the case of sulphur dioxide, but it is perhaps noteworthy that for pressures of carbon dioxide greater than 150 mm. the theoretical relationship holds for $m = 8 \times 10^{-11}$, $k_{CO_2} = 0·90$, and $R = 30·0$ (Table VI). It must be remembered that m, involving the rate of removal of bromine atoms at the wall, must depend on the nature of the wall, and this may alter appreciably as the pressure of the easily adsorbed gases sulphur dioxide and carbon dioxide increases. At higher pressures, the value of m may approach a constant value, not necessarily the same as in the case of the less easily adsorbed permanent gases nitrogen, oxygen, etc., and therefore the carbon dioxide coefficient 0·90 is considered comparable with the corresponding coefficients for the other gases. A table of triple collision coefficients has recently been given by Ritchie (this vol., p. 857); the above values may here be compared with values already obtained for the Br-Br combination, k_{N_2} being taken as unity:

Method.	Br_2.	CO_2.	O_2.	N_2.	A.	H_2.	Ref.
Absorption decrease ...	—	2·16	1·28	1·00	0·52	0·85	Rabinowitch and Wood, *Trans. Faraday Soc.*, 1937, **36**, 907.
HBr photosynthesis ...	—	(1·387)	1·38	1·00	0·64	0·51	Ritchie, *Proc. Roy. Soc.*, 1934, *A*, **146**, 828.
Budde effect	1·25	1·13	1·12	1·00	0·63	0·75	Present results.

The relative values are in approximate agreement with those determined by the other methods and indicate the general applicability of the treatment.

In the case of helium, under the experimental conditions, the diffusion effect is predominant up to the highest pressure of helium employed (see Fig. 2); this in conjunction with the small triple collision efficiency for helium rendered the accurate determination of k_{He} out of the question.

The above type of calculation cannot be applied to varying pressures of bromine, in that alteration of bromine pressure alters the position of the source of the bromine atoms. With increasing pressure, for example, the region of absorption moves closer to the wall where the light enters; no constant value of m can be expected to apply to different bromine pressures.

The Effect of Pressure on the Thermal Conductivity of Bromine.

Equation 2 is based on the assumption that the thermal conductivity of a gas is independent of the pressure. Maxwell from a consideration of the kinetic theory of gases predicted that there should be no variation over a wide range of pressures; the thermal conductivity will, however, decrease if the pressure is lowered so that the mean free path becomes comparable with the size of the vessel. The results of Senftleben and Riechemeier (*Ann. Physik*, 1930, **6**, 112) show that with hydrogen under the experimental conditions the thermal conductivity did not reach a steady value even at a pressure of 100 mm. With argon the thermal conductivity became constant when the pressure was about 10 mm. The variation of the thermal conductivity of bromine was therefore examined for different pressures under our experimental conditions. The experiments performed depended on the fact that, when a hot wire is suspended in a gas-containing vessel the walls of which are at a lower temperature than the wire, heat flows from the wire to the walls. Increase in the conductance causes an increase in the heat flow. This cools the wire and lowers its resistance. Senftleben and Germer (*ibid.*, 1929, **2**, 847) have shown that platinum wire may be used with bromine without fear of chemical interaction.

Experiment.—The apparatus used was the same as that shown in Fig. 1 except that the vessel V was replaced by a tube 20 cm. by 3 cm. This was kept in an electrically heated thermostat maintained at 25° (± 0·01°). A platinum wire 0·015 mm. in diameter and 7 cm. long was suspended in the tube. The leads, pinch-sealed into the tube, consisted of borated copper wire encased in glass capillaries. The copper wire was spot-welded to platinum wire of 0·5 mm. diameter, which in turn was welded to the gauge wire. Before any experimental measurements were made, the gauge wire was glowed for some time in bromine vapour.

The method adopted was to keep the applied voltage constant and measure the change in resistance as the pressure was varied. Bromine, the pressure of which was measured by means of the calibrated Bourdon gauge system, was then admitted to the tube. The resistance of the wire decreased and the change of resistance Δr with different pressures of bromine was thus observed.

The thermal conductivity of bromine reaches a constant value when the pressure is between 2 and 3 mm. Hence with the pressures used in the examination of the photo-expansion of bromine it is safe to say that the thermal conductivity coefficient K_{Br_2} was constant.

The Effect of Water Vapour.

The possible effect of water vapour on the Budde effects in bromine and chlorine has often been investigated. Ludlam (*Proc. Roy. Soc. Edin.*, 1924, **44**, 197) concluded that dry bromine exhibited no Budde effect and suggested that the energy absorbed was re-radiated. Lewis and Rideal (J., 1926, 583) maintained that, since the presence of moisture seemed necessary for the expansion, the effect was due to the photo-sensitive hydrate Br_2,H_2O. They showed the photo-expansion to be proportional to the partial pressures of bromine and water vapour, and advanced a mechanism of excitation and decomposition of these hydrate molecules as the explanation of the effect.

On the other hand, Brown and Chapman (J., 1928, 560) maintained that drying does not diminish the photo-expansion to any great extent with a mixture of air and bromine, contrary to the results of Lewis and Rideal. Matthews (*Trans. Faraday Soc.*, 1929, **25**, 41) found that, although there was a diminution in the Budde effect on drying bromine, it did not disappear entirely, though Ludlam and Mooney later pointed out (*Proc. Roy. Soc. Edin.*, 1929, **49**, 256) that, since in Matthews' experiments liquid bromine at constant temperature was in contact with the vapour, any photo-expansion observed would be due to the slight time lag in establishing equilibrium, and the pressure above the liquid would always be the same. They further suggested that in the event of there being no adsorbed film of water on the surface of the containing vessel, then recombination of the halogen atoms would take place on the walls. The heat of recombination would be dissipated, the heat capacity of the walls being very much greater than that of the gas. They also found that the energy absorbed by the bromine was not re-radiated as fluorescence at the pressure used (64 mm.).

Kistiakowsky (*J. Amer. Chem. Soc.*, 1929, **51**, 1395) found that careful purification and

drying of bromine and chlorine produced no change in the photo-expansion. Removal of the adsorbed film of water from the walls by "baking-out" the containing vessel at 300° made little or no difference. Inside the vessel was placed an almost hair-fine capillary, through which a platinum wire was drawn. The arrangement was such that only glass was in contact with the halogen vapour, the ends of the wire being carried to the outside of the vessel. The wire was used as a platinum resistance thermometer, the temperature change agreeing fairly well with the expansion on illumination. Martin, Cole, and Lent (*J. Physical Chem.*, 1929, **33**, 148), using chlorine at atmospheric pressure, concluded that careful purification and drying and the "baking-out" of the insolation vessel had no appreciable effect on the expansion.

On the other hand, Narayana (*Indian J. Physics*, 1934, **9**, 91) showed that in pure super-dried chlorine there was no photo-expansion. He further showed that, as the halogens chlorine and bromine were gradually dried, a marked decrease in the photo-expansion could be observed. The Budde effect in iodine (*idem, ibid.*, p. 111) was found to be greater at 200° than at 350°, this being attributed to the fact that at 200° the adsorbed film of water was still present on the walls, whereas at 350° it was assumed absent, the dry walls catalysing the atomic recombination.

Several investigators (Le Blanc, *Z. Elektrochem.*, 1919, **25**, 234; Halban and Siedentopf, *Z. physikal. Chem.*, 1922, **103**, 73; Kornfeld and Steiner, *Z. Physik*, 1937, **45**, 325) have failed to detect any difference between the absorption coefficients of moist chlorine and that which has been thoroughly dried. Martin, Cole, and Lent (*J. Physical Chem.*, 1929, **33**, 148) examined the scattering of light by moist and by dry chlorine. Both scattered it normally, *i.e.*, the intensity of the scattered light agreed with that calculated from the Rayleigh formula, and was a thousandfold less than the hypothetical fluorescence. Kistiakowsky (*J. Amer. Chem. Soc.*, 1927, **49**, 2194) found that extreme drying of chlorine did not appreciably alter the structure of the absorption spectrum or the total amount of energy absorbed. The fluorescence of dried chlorine was at most only a small percentage of the absorbed energy. He concluded that dissociation in the region of continuous absorption was independent of purity. Weigert and Nicolai (*Z. physikal. Chem.*, 1928, **131**, 267) considered that the similarity of absorption in moist and in very dry chlorine indicated considerable fluorescence if the absence of expansion in dry chlorine was proved.

Considering the question on the basis of the previous sections, it is evident that small amounts of water vapour cannot produce any appreciable increase in the number of bromine atoms recombining either through increase in the number of triple collisions with water as a third body, or through a decrease in the rate of diffusion to the walls. The triple collision efficiency of the water molecule will be of the same order as that of the bromine molecule itself. On the other hand, it is evident from Tables I—VI that at the pressure of bromine used in the present experiments (30—50 mm.) a large fraction of the bromine atoms was removed at the surface of the reaction vessel, and it was therefore conceivable that adsorbed water molecules might produce surface changes responsible for the conflicting results recorded by different observers. Discussion of these would involve a knowledge of the dimensions of, and treatment accorded to, the reaction vessels employed. The question was therefore experimentally examined, the reaction vessel earlier described being used.

Particular attention was paid to the purification of the phosphoric oxide used to dry the bromine, the method of Finch and Peto (J., **1922**, **121**, **692**) being employed. The oxide obtained had no reducing action on silver nitrate or mercuric chloride. Bromine was purified as already described (p. 1681). The apparatus for drying the bromine and measuring its photo-expansion is shown diagrammatically in Fig. 1. T was a liquid-air trap which had a volume of approximately 100 c.c. at the lower end. This bulb contained pure phosphoric oxide, introduced by tube A. The tap grease used was Apiezon L; it was exposed to bromine for some time before being used to grease the taps T_1, T_2, T_3, any absorption of bromine which might take place during an experiment thus being eliminated. The use of any form of tap grease is not ideal, but the results obtained appear to be quite definite.

The apparatus was evacuated by means of a mercury diffusion pump, backed by a Cenco Hyvac oil-pump. With this system a pressure of 2×10^{-6} mm. mercury (measured by a McLeod gauge) was easily obtained.

The light source was an Osram 500 watt projector lamp, run at 220 volts from 230 volt mains by hand-controlled resistance, and placed at a distance of 40 cm. from the centre of the insolation vessel. Heating rays were removed by interposing a 14 cm. layer of water.

Experimental Procedure.—The apparatus was evacuated, and the insolation vessel washed out with bromine vapour. Re-evacuation was followed by introduction of bromine vapour into the vessel to a pressure of 30 mm. The position of the gauge pointer on the eyepiece scale having been noted, the bromine was illuminated, and the increase of pressure observed. The pointer moved to its maximum reading about 20 seconds after illumination and returned to its original position after the light had been cut off. This process was repeated several times, the mean value of the measured increases of pressure being recorded. Finally the bromine was pumped off.

Meanwhile liquid or solid bromine, in *T*, was in constant contact with phosphoric oxide. (The halogen was frozen out periodically on to the phosphoric oxide with a carbon dioxide-acetone freezing mixture.) This contact was maintained during 3 months, measurement of the photo-expansion obtained with 30 mm. of bromine being made once a week.

The experimental results are in Table VII. All experiments were carried out at room temperature.

TABLE VII.

No. of hours dried.	$[Br_2]$, mm.	Increase in pressure, mm.	No. of hours dried.	$[Br_2]$, mm.	Increase in pressure, mm.	No. of hours dried.	$[Br_2]$, mm.	Increase in pressure, mm.
0	29·4	0·286	704	29·3	0·260	1278	29·9	0·234
72	30·3	0·312	894	30·6	0·260	1538	30·0	0·260
288	29·7	0·234	1134	30·3	0·260	2000	29·9	0·260
392	29·5	0·260	1206	29·8	0·234			

No positive decrease in the photo-expansion of bromine on thorough drying over phosphoric oxide was obtained.

In a second series of experiments the photo-expansion of dry bromine in a "baked-out" vessel was examined. The apparatus was that used above (Fig. 1) with the addition of a side tube (*X*) with two taps to regulate the supply of water vapour. The insolation vessel was heated in an asbestos hot-air bath by a bunsen burner, the flow of gas being regulated by means of a screw-clip. The "baking-out" was done by heating to 350° (this temperature, measured by a thermometer enclosed in the bath, was easily maintained and was considered sufficiently high to remove the adsorbed film of water from the vessel walls) and evacuating continuously with a mercury diffusion pump, backed by an oil pump, for 2 days. The bath was then removed, and dry bromine introduced into the insolation vessel to a pressure of 30 mm.

The results obtained were :—

	$[Br_2]$, mm.	Photo-expansion, mm.
Prior to drying bromine and "baking-out" insolation vessel	30·0	0·260
After drying bromine and "baking-out" insolation vessel	30·0	0·260

The experiment was repeated, the same result being obtained.

The bromine was then removed from the vessel *V* by freezing out with liquid air. Water vapour from *X* was admitted to *V*, and the pressure measured by the calibrated gauge system. Bromine vapour at a pressure of 30 mm. was now added, and the photo-expansion observed. The bromine–water vapour mixture was then pumped off, more water vapour added, and the process repeated.

Results : $[Br_2] = 30$ mm.

$[H_2O]$, mm.	0	2·1	3·7	6·5
Photo-expansion, mm.	0·260	0·247	0·234	0·260

Thus no increase in the photo-expansion was observed on adding water vapour to dry bromine.

DISCUSSION.

Changes in diffusion and gaseous thermal conductivity would be negligibly small for the small amounts of water vapour added. In general, we may distinguish between two possible primary processes at the wall, the adsorption of single atoms and the recombination of atoms by triple collision with the wall acting as third body. The former is considered predominant for the conditions in question, since the calculations of Tables I—VI are based on a rate of bromine atom removal proportional to the first power of the atom concentration,

and not to the square of that concentration, a conclusion supported by studies of the photosynthesis of hydrogen bromide, where the rate of HBr formation is proportional to $I_{abs.}$ when surface action is predominant. In any case, the efficiency of a triple stabilising collision such as the above approaches unity (Rabinowitch, *loc. cit.*) and adsorbed film is not likely to reduce it appreciably. On the other hand, the adsorption of a bromine atom by the wall may reasonably be expected to depend on the nature of the wall. The amount of water vapour introduced with the " dry " bromine in our experiments cannot appreciably alter the wall even if every water molecule were adsorbed (1 litre of gas properly dried by phosphoric oxide contains less than 2×10^{-6} g. of water); and hence, if the baking-out procedure employed is regarded as satisfactory, the efficiency of adsorption of bromine atoms on striking the wall must be the same whether the wall be wet or dry. This is then in agreement with the results of Schwab (*Z. physikal. Chem.*, 1934, **27**, *B*, 452), but offers no explanation of the conflicting results recorded by different workers. It may be pointed out that illumination over a prolonged period may be necessary before equilibrium wall conditions are attained with respect to the bromine atoms, such equilibrium depending on, *inter alia*, the intensity of illumination: the accommodation coefficient of the walls will then depend on the conditions and will thus affect the rate at which heat is conducted away through the wall from the gas mixture. How far such effects show themselves in the observed Budde effect must be a matter for further experiment. The methods of purification of the materials used are of the highest importance, the concentration of atoms being very small and thus affected by correspondingly small amounts of impurity; it is possible that the conflicting results previously recorded are due to traces of impurities introduced with the drying agents.

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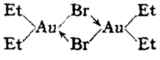
UNIVERSITY OF EDINBURGH. [*Received, July 28th*, 1937.]

353. *The Constitution of Diethylmonobromogold and Di*-n-*propylmonocyanogold.*

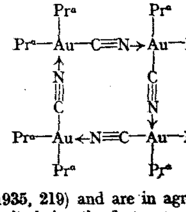
By A. BURAWOY, C. S. GIBSON, G. C. HAMPSON, and H. M. POWELL.

The dipole moments of diethylmonobromogold and di-*n*-propylmonocyanogold have been accurately determined in carbon tetrachloride solution. These two symmetrically constituted compounds have small but definite dipole moments. The crystallographic examination of diethylmonobromogold shows that the atoms and groups attached to a tervalent and quadricovalent gold atom are coplanar with the gold atom.

THE symmetrical constitutional formulæ assigned to diethylmonobromogold (I) and di-*n*-propylmonocyanogold (II) have been based on molecular-weight determinations (Gibson



(I.)



(II.)

and co-workers, J., 1930, 2531; 1934, 860; 1935, 219) and are in agreement with our knowledge of electronic structure. Apart from its being the first organo-gold compound

to be isolated (J., 1907, **91**, 2061), compound (I) is the simplest of the series, and compound (II) is of a more complicated type to which a certain interest is attached. Being both colourless and soluble in non-polar solvents, they lend themselves to physical investigation.

The dielectric constants were measured in a platinum-plated condenser of design similar to that described by Jenkins and Sutton (J., 1935, 609). The following results were obtained for solutions in carbon tetrachloride at 25°, the symbols having their usual significance.

Diethylmonobromogold.

f_2.	d.	e.	n^2.	P_2.	$_EP_2$.
0·006259	1·6044	2·2498	2·14310	126·6	89·8
0·004102	1·5975	2·2417	2·13976	126·6	90·7
0·0	1·5844	2·2264	2·13289	—	—

$_{A+O}P_2$ = 126·6 − 90·3 = 36·3 c.c. μ = 1·32 D.

Di-n-propylmonocyanogold.

f_2.	d.	e.	n^2.	P_2.	$_EP_2$.
0·0063886	1·6026	2·2551	2·14703	249·7	204·3
0·0058538	1·6012	2·2528	2·14615	249·7	204·9
0·0	1·5847	2·2266	2·13289	—	—

$_{A+O}P_2$ = 249·7 − 204·6 = 45·1 c.c. μ = 1·47 D.

Since the electron polarisation of the first compound previously found (J., 1935, 221) in benzene is different from that now obtained in carbon tetrachloride, the refractivities were again determined in benzene.

Refractivities of diethylmonobromogold in benzene at 25·0°.

f_2.	d.	n^2.	$_EP_2$.
0·010514	0·9269	2·27203	90·7
0·006884	0·9086	2·26703	90·7
0·0	0·87355	2·25797	—

The electron polarisation is thus substantially the same in both solvents, and the value of the dipole moment of the compound in benzene previously found is somewhat low.

These substances furnish two more examples of compounds having symmetrical constitutions and possessing dipole moments differing appreciably from zero. The determination of the cause or the explanation of the positive electric moments of symmetrical molecules is still under discussion (see, *e.g.*, papers in *Trans. Faraday Soc.*, 1934, **30**; Sugden, p. 734; H. O. Jenkins, p. 739; Hampson, p. 877; also Hammick, Hampson, and G. I. Jenkins, *Nature*, 1935, **136**, 990; H. O. Jenkins, J., 1936, 862; *Ann. Reports*, 1936, **33**, 133). In view of the fact that many symmetrically constituted compounds having dipole moments of the order of 1 D are known, and their high molecular weights being borne in mind, it must be concluded that the dipole moments of diethylmonobromogold and di-*n*-propylmonocyanogold are in agreement with the symmetrical constitutions (I) and (II) assigned to them.

Preliminary crystallographic investigation of diethylmonobromogold some five years ago having indicated that the bromine atoms and ethyl groups in this compound are coplanar with the gold atoms, it was clear that it is impossible to effect the optical resolution of a 4-covalent and tervalent gold compound having four different atoms or groups attached to the gold atom. The complete investigation of diethylmonobromogold was delayed for a number of reasons, one being the superficial decomposition of the compound by *X*-rays (see below). In the meantime, Cox and Webster (J., 1936, 1635) completed the crystallographic investigation of potassium bromoaurate, $KAuBr_4,2H_2O$, and showed that the four bromine atoms in this salt are coplanar with the gold atom. From this result and that of the crystallographic investigation of diethylmonobromogold, we now know that both in its inorganic and in its organic compounds the tervalent and 4-covalent gold atom exhibits a planar distribution of valencies. The crystallographic investigation has also confirmed the correctness of the constitution assigned to diethylmonobromogold.

Diethylmonobromogold crystallises from ligroin (b. p. 35—40°) in colourless anorthic needles, which are very soft and so easily flexible that normal manipulation of the solution frequently results in bending of the crystals into hook- or loop-shaped forms. The only

faces distinguishable with certainty lie along the needle zone and are (100), (010), and ($1\bar{1}0$). The crystals show extremely high negative double refraction with oblique extinction on all faces and the lesser refractive index always for the ray most nearly along the needle direction.

Oscillation photographs were obtained with a small needle oscillating about the c and b axes, copper radiation being used. The unit cell dimensions deduced from these are: $a = 9{\cdot}63$, $b = 9{\cdot}33$, $c = 4{\cdot}98$ A.; $\alpha = 121^\circ\ 10'$, $\beta = 89^\circ\ 6'$, $\gamma = 105^\circ\ 48'$, and the density calculated for two molecules of $AuEt_2Br$ is 3·07 g./c.c. There is no evidence from crystal form or pyroelectric effect of the absence of a symmetry centre, and the space group is taken to be $\bar{1}$.

It was impossible to obtain a wholly satisfactory set of photographs for intensity comparisons. The material used shortly after its preparation had darkened slightly, and this superficial decomposition increased under the action of the X-rays, the crystals becoming coloured dark violet. Owing to this action and the necessity for setting the crystal by X-ray methods, great reliance cannot be placed on the observations. An accurate structure has not been deduced, but sufficient qualitative information has been obtained to suggest the general form of the molecule.

The extreme softness of the crystals and the general appearance of the X-ray photographs indicate that a molecular lattice is present. Strong reflexions are obtained at low angles of reflexion, but intensities fall off rapidly with increasing angle θ, showing that there is a large temperature factor diminution. The photographs contrast sharply with those obtained from diethylthallium bromide, which forms a distorted sodium chloride type of structure with $TlEt_2^+$ and Br^- ions and gives strong high-order reflexions.

All arrangements of the atoms within the cell having gold and bromine in special positions without parameters are definitely excluded by irregularities in the main series of reflexions which could not be thus explained. All atoms are therefore in general positions, *e.g.*, Au in xyz, $\bar{x}\bar{y}\bar{z}$; Br in $x'y'z'$, $\bar{x}'\bar{y}'\bar{z}'$. By means of contour diagrams for reflexions $h00$ and $0k0$, the whole range of possible values for x, x', and y, y' was explored, and the parameters limited to a comparatively small region. In making a choice of values the requirements of reflexions $hk0$ were also taken into account. In arriving at these approximate parameters the contributions of the carbon atoms have been ignored since they will be small and, in general, will tend to cancel, but they may have an appreciable influence on the relative intensities of weaker reflexions of small θ value. The parameters z and z' were estimated from consideration of relative intensities of $00l$ for which there are, however, few observations owing to the small spacing, and by use of $h0l$ reflexions, the x and x' values previously found being assumed. Although there are discrepancies in detail, the main variations in intensity are accounted for by the parameters chosen, and the agreement is probably as good as could be expected.

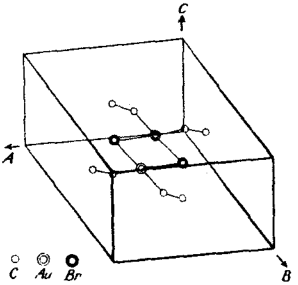
The parameters found are: Au, $x = 0{\cdot}13$, $y = 0{\cdot}125$, $z = -0{\cdot}085$; Br, $x' = 0{\cdot}15$, $y' = -0{\cdot}12$, $z' = 0{\cdot}045$, and calculated and observed relative intensities are given in the table.

	I, calc.	*I*, obs.		*I*, calc.	*I*, obs.		*I*, calc.	*I*, obs.		*I*, calc.	*I*, obs.
100	58	vvs	040	12·4	s—vs	330	1·2	nil	410	7·7	w
200	1·1	m	050	3·9	m—	440	5·2	w	510	0	w
300	23·9	vs	060	2·2	w	$1\bar{1}0$	51·7	vvs	610	4·4	w
400	17·2	s	001	44	vs	$2\bar{2}0$	5·0	ms	120	2·5	s
500	2·3	vw	002	9	vs	$3\bar{3}0$	9·2	s	130	9·4	vs
600	1·1	mw	003	0·2	nil	$4\bar{4}0$	10·0	vs	140	4·3	m
700	4·1	mw	004	0·2	nil	$5\bar{5}0$	2·8	m—ms	111	9·2	s
010	55	vs	110	5·5	nil	210	6·9	s	211	0·8	w
020	0	m	220	2·9	w	310	16·8	ms	311	10	ms
030	11·4	vs									

The orientation of the molecule in the unit cell is indicated in the perspective diagram (Fig. 1) where, for convenience, the origin has been moved to $\frac{1}{2}\ \frac{1}{2}\ \frac{1}{2}$. The molecule projected on the plane of the gold and bromine atoms is shown in Fig. 2. The carbon atoms marked $\oplus$ and $\ominus$ are respectively above and below the plane of the other atoms. The distances marked on Fig. 2 are subject to a probable error of $\pm$ 0·1 A.

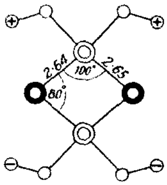
The results show that two gold atoms and two bromine atoms lie close together near the origin and that the molecule is $Au_2(C_2H_5)_4Br_2$. These four atoms form a rough square in a plane somewhat inclined to (001). In order that the molecule may fit into the unit cell,

Fig. 1.



Unit cell and molecule. Origin at ½ ½ ½.

Fig. 2.



all the atoms must lie approximately in one plane as is shown by the very small *c* dimension, and the four gold valencies must accordingly lie in one plane and will be approximately at right angles to one another.

With the two ethyl groups attached to each gold atom in this way, the molecule fits into the cell satisfactorily, but probably two of the terminal carbon atoms are slightly above the plane of the rest of the molecule and the other two in corresponding positions below this plane as indicated in the figure, leaving the molecule with a centre of symmetry. This displacement of the terminal carbon atoms is necessary to prevent a too close approach of atoms in adjacent molecules.

The suggested structure is in agreement with the needle habit of the crystals and the very high negative double refraction with the smallest refractive index roughly along the needle direction.

Grants from Imperial Chemical Industries Limited and from the Government Grants Committee of the Royal Society are gratefully acknowledged. One of us (A. B.) is also indebted for a maintenance grant from the Society for the Protection of Science and Learning.

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The Dyson Perrins Laboratory and the Mineralogy Department,
University of Oxford. [*Received, August 30th*, 1937.]

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354. *Preparation of the Simpler α-Alkylamino-acids. Part I.*

By Wesley Cocker.

The method used by Cocker and Lapworth (J., 1931, 1894) for the synthesis of sarcosine has been extended to the preparation of a number of other alkylamino-acids, and rendered more economical by the use of magnesium sulphate in place of zinc sulphate as precipitant for benzenesulphonic acid (compare Lapworth and Morriss, B.P. 14,402, 1915).

Although Cocker and Lapworth (*loc. cit.*) realised that in the preparation of sarcosine, after the hydrolysis of its benzenesulphonyl derivative, the benzenesulphonic acid could be removed as its magnesium salt (Lapworth and Morriss, *loc. cit.*), its removal as zinc salt was described because of difficulties in the complete precipitation of magnesium from solution. Later investigation has shown that magnesium hydroxide is insoluble in excess

of barium hydroxide solution and thus the excess of magnesium sulphate required to precipitate benzenesulphonic acid may be completely removed by excess of barium hydroxide. The preparations of *N*-ethyl- and *N*-propyl-glycine and *N*-methylalanine are quite straightforward. On the other hand, attempts to prepare *N*-benzylglycine yielded only glycine, and this is considered to be due to debenzylation of *N*-benzenesulphonyl-*N*-benzylglycine rather than *N*-benzylglycine. The only evidence for this view is the fact that treatment of the *N*-benzenesulphonyl-*N*-benzyl derivative with hydriodic acid yields benzyl iodide more quickly than phenyl mercaptan. Glycine was not obtained by hydrolysis of *N*-benzenesulphonyl-*N*-allylglycine with sulphuric acid.

Experimental.

Preparation of Sarcosine.—Benzenesulphonylsarcosine (40 g.) is hydrolysed with 60% sulphuric acid, and the product treated with magnesium sulphate (38 g.) in water (40 c.c.). The mixture is agitated and cooled to 0°, and the precipitated magnesium benzenesulphonate collected on glass wool and washed with a saturated solution of magnesium sulphate. The combined filtrates are made neutral to Congo-red, again filtered, concentrated to 50 c.c., and treated with barium hydroxide (70 g.). The precipitated magnesium hydroxide is removed, and sarcosine, m. p. 211—212°, isolated from the filtrate as described by Cocker and Lapworth (*loc. cit.*). Yield, 11·2—11·3 g. (74—76% of the theoretical).

Preparation of Other α-Alkylamino-acids.—(1) N-*Ethylglycine.* Benzenesulphonylglycine (25 g.) is dissolved in 3N-sodium hydroxide (80 c.c.) and shaken with ethyl iodide (32 g.; 2 mols.). The solution is acidified and the *N*-benzenesulphonyl-*N*-ethylglycine obtained is washed with a solution of sodium thiosulphate and with water, and recrystallised from hot water; m. p. 115·5—116° (compare Johnson and McCollum, *Amer. Chem. J.*, 1906, **35**, 61). Yield, 24·2 g. (85% of the theoretical).

The above compound (38·5 g.) is boiled under reflux for 5 hours with dilute sulphuric acid (42 c.c. of the conc. acid and 52 c.c. of water). After cooling, 6 g. of unhydrolysed material are removed. From the filtrate, *N*-ethylglycine is isolated by the method described above or by Cocker and Lapworth (*loc. cit.*). Yield, 9·47 g. (70%, calc. on the material hydrolysed); m. p. 180—182° (decomp.) [Heintz, *Annalen*, 1864, **129**, 35, gives m. p. 160° (decomp.)] (Found: N, 13·7. Calc.: N, 13·6%). The *phenylhydantoin*, prepared by the usual method, crystallises from benzene–ligroin in six-sided prisms, m. p. 110°, soluble in alcohol and benzene (Found: N, 14·1. $C_{11}H_{12}O_2N_2$ requires N, 13·7%).

(2) N-*Propylglycine.* Benzenesulphonylglycine (23·5 g.), dissolved in 3N-sodium hydroxide (75 c.c.), is refluxed for 24 hours with *n*-propyl iodide (24 g.; 1·5 mols.). From the solution, by acidification, *N*-benzenesulphonyl-*N*-propylglycine is obtained as a white solid; it is washed with water, dried in a vacuum, and recrystallised from benzene–ligroin. Yield, 20 g. (72% of the theoretical); m. p. 99—100° (compare Johnson and McCollum, *loc. cit.*) (Found: N, 5·45. Calc.: N, 5·45%).

The above compound (30 g.) is boiled under reflux for 12 hours with a mixture of 30 c.c. of concentrated sulphuric acid and 37 c.c. of water. From the solution, 13·7 g. (61% of the theoretical yield) of *N*-propylglycine are obtained in long prisms or needles, m. p. 196—198° (decomp.), readily soluble in water and hot alcohol (Found: N, 11·8. Calc.: N, 12·0%). Chancel (*Bull. Soc. chim.*, 1892, **7**, 410) prepared it from ethyl bromoacetate and *n*-propylamine, but gave no yield or m. p. The *benzoyl* derivative, readily prepared by the method described by Cocker and Lapworth (*loc. cit.*) for benzoylsarcosine, crystallises from benzene–ligroin in flat hexagonal plates, m. p. 89—90°, readily soluble in ether, water, and chloroform. In aqueous solution it is acid to litmus (Found: N, 6·4. $C_{12}H_{15}O_3N$ requires N, 6·3%). The phenylcarbamido-derivative, m. p. 132° (decomp.), forms colourless prisms, soluble in hot water and alcohol, but sparingly in benzene.

(3) N-*Methylalanine.* Benzenesulphonylalanine (16 g.), prepared from alanine in 80% yield, is methylated with methyl sulphate (18 g.), giving *N*-benzenesulphonyl-*N*-methylalanine (15·4 g.; 90%), m. p. 95—96°, in small needles or prisms which are readily recrystallised from benzene–ligroin.

The above compound (26·9 g.) is boiled under reflux with a mixture of 28·5 c.c. of concentrated sulphuric acid and 35 c.c. of water for 14 hours; after removal of 2 g. of unhydrolysed material, *N*-methylalanine (8·07 g.) is isolated from the filtrate in 81% yield (calc. on the material hydrolysed), m. p. 315—317° (decomp.). It is freely soluble in water but only sparingly in alcohol and is best purified from a mixture of the two (Found: N, 13·7. Calc.: N, 13·6%). Lindenberg

(*J. pr. Chem.*, 1875, **12**, 244) gives m. p. 260° (decomp.). The *benzoyl* derivative crystallises from benzene in flat, colourless, transparent plates, m. p. 129—129·5°, readily soluble in water, in which it gives an acid reaction (Found : N, 6·85. $C_{11}H_{13}O_3N$ requires N, 6·8%). The *benzenesulphonyl* derivative, m. p. 96—97°, forms long needles or prisms from benzene (Found : N, 5·6. $C_{11}H_{13}O_4NS$ requires N, 5·5%). The *phenylhydantoin* crystallises in colourless four-sided plates, m. p. 145—6°, from hot water (Found : N, 13·9. $C_{11}H_{12}O_2N_2$ requires N, 13·7%).

(4) *Attempts to prepare* N-*benzylglycine.* *N*-Benzenesulphonyl-*N*-benzylglycine is readily prepared in theoretical yield from benzenesulphonylglycine and benzyl iodide (2 mols.); with benzyl chloride (2 mols.), the yield is 62%. It crystallises from benzene or 75% alcohol in colourless silky needles, m. p. 124·5—125·5° (compare Johnson and McCollum, *loc. cit.*).

When the compound (30 g.) is refluxed for 10 hours with a mixture of 24 c.c. of concentrated sulphuric acid and 29 c.c. of water, 10 g. remain unhydrolysed and 3·5 g. of glycine, m. p. 255° (decomp.), are obtained (benzenesulphonyl derivative m. p. and mixed m. p. 165—166°).

The compound is unchanged by 45% sulphuric acid, and almost unchanged by dilute hydriodic acid (1 : 1) at water-bath temperature. With more concentrated hydriodic acid it yields benzyl iodide, quickly followed by phenyl mercaptan.

The author thanks Professor A. Lapworth, F.R.S., for his interest during the investigation.

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355. *Preparation of the Simpler α-Alkylamino-acids. Part II.*

By WESLEY COCKER.

The method of Johnson and Ambler (*J. Amer. Chem. Soc.*, 1914, **36**, 371) for the preparation of sarcosine by the decomposition of its *N*-benzylsulphonyl derivative with hydrochloric acid is elegant, since the unwanted product (benzyl chloride) is volatile and only sarcosine hydrochloride remains. The investigation now described was an attempt to extend the above principles by the use of the derivatives of other sulphonic acids known to be unstable in hot acid, yielding volatile products. Amino-acid derivatives of 2-methoxynaphthalene-1-sulphonic acid, mesitylenesulphonic acid, and *m*-xylene-4-sulphonic acid have been prepared and from the last two compounds good yields of sarcosine and *N*-ethylglycine have been obtained.

PECHMANN (*Ber.*, 1873, **6**, 534) showed that benzylsulphonyl chloride dissociates almost quantitatively into sulphur dioxide and benzyl chloride on heating, and Johnson and Ambler (*loc. cit.*) found that benzylsulphonamides are transformed into benzyl chloride and sulphur dioxide when heated with hydrochloric acid at 130—150°. Crafts (*Ber.*, 1901, **34**, 1352) showed that *m*-xylene-4-sulphonic acid is unstable at comparatively low temperatures in presence of mineral acid, and Rasik Lal Datta (*J. Amer. Chem. Soc.*, 1921, **43**, 310) obtained trichloromesitylene by leading chlorine through mesitylenesulphonic acid. Hoogewerf and van Dorp (*Rec. trav. chim.*, 1902, **21**, 359) showed that mesitylenesulphonic acid gives mesitylene when heated with 50% acetic acid. Lapworth (*Chem. News*, 1895, **71**, 206) found that potassium 2-ethoxy- and 2-methoxy-naphthalene-1-sulphonates are decomposed by boiling water to 2-ethoxy- and 2-methoxy-naphthalene. It has now been found that on hydrolysis of *N*-*m*-xylene-4-sulphonylsarcosine and *N*-mesitylenesulphonylsarcosine with 60% sulphuric acid xylene and mesitylene, particularly the latter, are readily evolved; the results obtained by the use of 2-methoxynaphthalene-1-sulphonyl derivatives were not encouraging. In neither of the successful hydrolyses was sulphur dioxide evolved, but presumably sulphuric acid was produced, and the amino-acid was readily isolated. There is insufficient evidence to state what is the mechanism of hydrolysis, since two are possible :

$$\begin{array}{ccccc} NHMe{\cdot}CH_2{\cdot}CO_2H & & & & \\ + & & & & \\ C_9H_{11}{\cdot}SO_3H & \xleftarrow{H_2SO_4} & C_9H_{11}{\cdot}SO_2{\cdot}NMe{\cdot}CH_2{\cdot}CO_2H & \xrightarrow{H_2SO_4} & C_9H_{12} + SO_3H{\cdot}NMe{\cdot}CH_2{\cdot}CO_2H \\ \downarrow & & & & \downarrow \\ C_9H_{12} + H_2SO_4 & & & & H_2SO_4 + NHMe{\cdot}CH_2{\cdot}CO_2H \end{array}$$

In either case there is at some stage attack of proton at the nuclear carbon atom to which $SO_2{\cdot}NX$ is attached, a reaction rendered facile by the accumulative effect of the methyl groups in mesitylene.

EXPERIMENTAL.

(A) *Attempted Preparation of Sarcosine from its 2-Methoxynaphthalene-*1*-sulphonyl Derivative.*—N-2-*Methoxynaphthalene*-1-*sulphonylglycine*, prepared in 93% yield from the sulphonyl chloride in benzene and glycine in *N*-sodium hydroxide, consists of six-sided plates, m.p. 184·5° (instantaneous m.p.), soluble in benzene, alcohol and ethyl acetate (Found: N, 4·9. $C_{13}H_{13}O_5NS$ requires N, 4·7%).

N-2-*Methoxynaphthalene*-1-*sulphonylsarcosine*, prepared in 90% yield from the above compound by methylation with methyl sulphate, consists of transparent rectangular prisms, m.p. 145°, soluble in hot water and alcohol (Found: C, 54·45; H, 5·05; N, 4·7. $C_{14}H_{15}O_5NS$ requires C, 54·4; H, 4·85; N, 4·5%). Attempted hydrolysis with boiling 60% sulphuric acid produced a little 2-methoxynaphthalene and much tar. A little sarcosine was obtained as the phenylcarbamido-derivative. Below 125° the hydrolysis scarcely proceeded at all.

(B) *Preparation of Sarcosine from its Mesitylenesulphonyl Derivative.*—*Mesitylenesulphonylglycine*, prepared from the sulphonyl chloride (Demény̆, *Rec. trav. chim.*, **1931**, **50**, 55) and glycine in the manner described above, consists of long, colourless, transparent prisms, m.p. 154·5°, soluble in hot water and benzene (Found: N, 5·6. $C_{11}H_{15}O_4NS$ requires N, 5·45%).

Methylation with methyl sulphate gives *mesitylenesulphonylsarcosine* in 80% yield as transparent feathery prisms, m.p. 164—165°, shrinking 157·5°, soluble in boiling water, alcohol and benzene (Found: N, 5·4. $C_{12}H_{17}O_4NS$ requires N, 5·2%).

Hydrolysis. The latter compound (37·5 g.), suspended in a mixture of 38 c.c. of concentrated sulphuric acid and 45 c.c. of water, is heated to boiling in a Claisen flask, carbon dioxide being passed in to facilitate removal of mesitylene and water added to keep the volume constant; the reaction is complete in 2 hours. Sarcosine is isolated from the solution, containing only sarcosine sulphate and sulphuric acid, by the method of Cocker and Lapworth (J., **1931**, 1397). The yield of almost pure sarcosine, m. p. 213° (decomp.), is 10·5—11 g. (85—90% of the theoretical) (Found: N, 15·7. Calc.: N, 15·7%).

(C) *Preparation of Sarcosine and* N-*Ethylglycine from their* m-*Xylene*-4-*sulphonyl Derivatives.*—By the method used by Deményi (*loc. cit.*) for mesitylenesulphonyl chloride, *m*-xylene-4-sulphonyl chloride is prepared in 50% yield from *m*-xylene and chlorosulphonic acid. *m-Xylene-4-sulphonylglycine, obtained in 75% yield, separates from hot water as the* monohydrate, m.p. 76° (Found: N, 5·6. $C_{10}H_{13}O_4NS,H_2O$ requires N, 5·4%). It loses water when heated for 10 minutes at its m.p. and then has m.p. 110°. It also loses water on recrystallisation from benzene. The anhydrous compound consists of long transparent prisms, m.p. 110—110·5°, soluble in alcohol, ether and hot benzene (Found: N, 5·8. $C_{10}H_{13}O_4NS$ requires N, 5·8%).

m-*Xylene*-4-*sulphonylsarcosine*, prepared in 75% yield by methylation of the preceding compound with methyl sulphate, consists of transparent prisms, m.p. 104·5—105°, soluble in hot water, benzene and high-boiling ligroin (Found: N, 5·6. $C_{11}H_{15}O_4NS$ requires N, 5·45%). It is best recrystallised from ligroin. When hydrolysed as described under (B), it yields 50—55% of sarcosine.

N-m-*Xylene*-4-*sulphonyl*-N-*ethylglycine* is obtained in 61% yield by heating a mixture of *m*-xylene-4-sulphonylglycine in 3*N*-sodium hydroxide and ethyl *p*-toluenesulphonate on the water-bath, with agitation. It consists of large transparent pyramids, m.p. 108—109° (Found: N, 5·3. $C_{12}H_{17}O_4NS$ requires N, 5·2%). Ethyl iodide gives a yield of 74% of the theoretical. Hydrolysis as under (B) gives *N*-ethylglycine in 34% yield, m.p. 181·5° (decomp.) (compare Cocker, this vol., p. **1693**; Heintz, *Annalen*, **1864**, **129**, 35) (Found: N, 13·8. Calc.: N, 13·6%) (benzenesulphonyl derivative, m.p. 116·5°; compare Johnson and McCollum, *Amer. Chem. J.*, **1906**, **35**, 61).

The author thanks Professor A. Lapworth, F.R.S., for his interest during the investigation.

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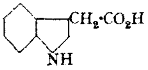
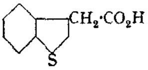
356. *Thionaphthen-2-acetic Acid.*

By Eric M. Crook and William Davies.

Thionaphthen-2-acetic acid (II) has been synthesised. Its growth-stimulating action on plants is less than that of the structurally related and naturally occurring indole-3-acetic acid (I). An isomeric thionaphthenacetic acid of unknown constitution has also been prepared and is slightly biologically active.

Indole-3-acetic acid or "heteroauxin" (I) has a great growth-stimulating action on plants as shown by the Avena and pea-curvature tests (*Ann. Reports*, 1935, 426) and is sometimes regarded as a "plant hormone." In view of the chemical similarities existing between some indole and thionaphthen derivatives, thionaphthen-2-acetic acid (II) has been prepared and its biological activity compared with that of (I). A preliminary communication on its hormonal action has been published by Crook, Davies, and Smith (*Nature*, 1937, **139**, 154).


(I.)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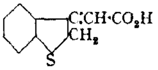
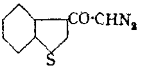

(III.)


(IV.)

The reaction product of indole and ethylmagnesium iodide condenses with chloroacetonitrile to give in excellent yield a nitrile which on alkaline hydrolysis gives (I) (Majima and Hoshino, *Ber.*, 1925, **58**, 2042). The analogous process with thionaphthen, however, when carried out either in ethyl ether or in anisole, gave no thionaphthen derivative. Accordingly the method (D.R.-P. 562,391) for introducing the acetic acid group directly (from halogenoacetic acids and their derivatives) into aromatic hydrocarbons was investigated with a view to applying it to thionaphthen. The experiments were carried out in glass vessels. Refluxing naphthalene with ethyl bromoacetate in the presence of aluminium powder ultimately yielded a mixture of acids melting at 115—120° and a ketonic material forming a *p*-nitrophenylhydrazone. The action of ethyl chloroacetate and aluminium chloride on naphthalene in boiling nitrobenzene solution gave no crystalline material. When naphthalene was boiled for 64 hours with a large excess of ethyl bromoacetate, a crude mixture of acids was obtained in small yield, from which α-naphthylacetic acid, m. p. 130°, was isolated. As shown by the equivalent weight, only a small quantity of naphthalenediacetic acid was produced; this is in marked contrast to the action of thionaphthen under the same conditions, where the main acid produced was shown by the equivalent weight (129·5) to consist largely of thionaphthendiacetic acid ($C_{12}H_{10}O_4S$ requires equiv. 125). Finally the presence of copper powder in the thionaphthen–ethyl bromoacetate mixture gave rise to a thionaphthenacetic acid, m. p. 141°, of which the constitution is not yet known.

The oxygen of indoxyl condenses with certain active methylene groups (D.R.-P. 255,691). Accordingly thioindoxyl was heated with malonic acid under various conditions with the object of preparing (III), which on isomerisation would give (II). The results were negative.

It is difficult to form a Grignard reagent from 2-bromothionaphthen in the ordinary way (cf. Komppa and Weckman, *J. pr. Chem.*, 1933, **138**, 109), but it can be done by Grignard's device (*Compt. rend.*, 1934, **198**, 625) of using a large quantity (more than 2 mols.) of a readily reactive halide, with the appropriate amount of magnesium to form compounds with both halides. In the present case the action of carbon dioxide on the mixture of 2-thionaphthenylmagnesium bromide and methylmagnesium iodide produced a 70% yield of thionaphthen-2-carboxylic acid. The corresponding acid chloride was converted by diazomethane into the diazo-ketone (IV); this on gradual treatment in alcoholic solution with small quantities of silver oxide (Arndt and Eisert, *Ber.*, 1935, **68**, 200; 1936, **69**, 1106, 1805) formed an ester which on hydrolysis gave the desired

thionaphthen-2-acetic acid (II), m. p. 109°. This work on thionaphthen derivatives is being continued.

Experimental.

Thionaphthenacetic Acid, m.p. 141°.—Thionaphthen (4 g.), ethyl bromoacetate (4 c.c.), and copper powder (2 g.) were refluxed for 35 hours, a further 2 g. of copper powder being added in small quantities about every 3 hours. The product was boiled with excess of alcoholic sodium hydroxide for 2 hours and diluted with cold water, and the copper compounds and unchanged thionaphthen separated. The filtrate was shaken with ether and acidified with hydrochloric acid, the organic acid extracted with ether, the extract evaporated, the tarry residue treated with hot water, and the aqueous solution purified with animal charcoal. On cooling, about 0·1 g. of brown platelets, m. p. 90—105°, separated (Found: equiv., 196. Calc. for $C_{10}H_8O_2S$: equiv., 192). Repeated crystallisation from water resolved the mixture into a less soluble fraction, m. p. 140—141°, and a more soluble impure acid, m. p. 60—90°, which crystallised in dull feathery needles. The thionaphthenacetic acid, m. p. 141°, crystallised from water in small plates with a pronounced silvery lustre and was readily oxidised by dilute potassium permanganate solution.

A thionaphthendiacetic acid, also of unknown constitution, was obtained in impure condition when thionaphthen (4 g.) and ethyl bromoacetate (5 c.c.) were refluxed in the absence of copper for 64 hours, the resulting ester hydrolysed, and the acid separated from the green fluorescent solution in the way described above for the acid, m. p. 141°. The diacetic acid finally separated from anisole in crystals, m. p. about 108°, very sparingly soluble in boiling petroleum (b. p. 80—100°) and in cold water and very soluble in cold 50% alcohol. It had no growth-stimulating action on decapitated oats (Avena test) (Found: equiv., 129·5. Calc. for $C_{12}H_{10}O_4S$: equiv., 125).

Thionaphthen-2-carboxylic Acid.—Thionaphthen, brominated in chloroform after Komppa (*J. pr. Chem.*, 1929, **122**, 319), gave a 90% yield of a very light yellow, highly refractive oil, b. p. 140°/18 mm., which remained unchanged in a corked bottle for 1½ years (according to Komppa it becomes bright red on keeping). 2-Bromothionaphthen (4 g.; 1 mol.) and methyl iodide (3 g.; 2 mols.) in ether were added to magnesium (0·9 g.; 3½ atoms) in ether, and the mixture refluxed. After the vigorous action had subsided, the mixture was boiled for a further 15 minutes and cooled, carbon dioxide passed in, and the product decomposed by ice and hydrochloric acid and worked up in the usual way. The thionaphthen-2-carboxylic acid (2·5 g.; 70% yield) crystallised from benzene in needles having the m. p. 174—175° recorded by Komppa and Weckman (*loc. cit.*).

Warm glacial acetic acid (4 c.c.) containing 0·2 g. of thionaphthen-2-carboxylic acid was cooled, perhydrol (30%; 1·5 c.c.) added, and the mixture heated on the water-bath for ½ hour after the addition of 1 c.c. of water. The liquid, diluted with its own volume of water and kept for 2 days, deposited clusters of yellow prisms, m. p. 218° (decomp.) of thionaphthen-2-carboxylic acid *S*-dioxide, which were recrystallised from water (Found: equiv., 207·7. Calc. for $C_9H_6O_4S$: equiv., 210).

Thionaphthen-2-acetic Acid.—Thionaphthen-2-carboxylic acid was converted quantitatively by thionyl chloride into the acid chloride, which formed needles, m. p. 53—54°, from light petroleum (Komppa and Weckman, *loc. cit.*, give m. p. about 50°). The acid chloride (1·5 g.) in dry ether (20 c.c.) was added to a dry ethereal (20 c.c.) solution of diazomethane made from 2 g. of nitrosomethylurea, and kept for 24 hours. The ether was then removed under reduced pressure, the yellow 2-thionaphthenyl diazomethyl ketone [prisms, m. p. about 140° (decomp.)] dissolved in absolute alcohol (100 c.c.), and the warm solution treated with shaking during an hour with small quantities of silver oxide mixed with alcohol, 4 g. of silver oxide being used. The mixture was boiled under reflux for an hour, and the liquid filtered and refluxed for 3 hours with potassium hydroxide solution (50%; 1 c.c.) and water (30 c.c.). The solution was concentrated under reduced pressure and acidified with hydrochloric acid, and the product crystallised from water. The yield was about 1 g., m. p. 100—105°. When an aqueous solution saturated at the ordinary temperature was kept for at least 24 hours, thionaphthen-2-acetic acid separated in long thin prisms, m. p. 109° (Found: equiv., 192. Calc. for $C_{10}H_8O_2S$: equiv., 192).

The University of Melbourne. [*Received, September 1st, 1937.*]

357. *Studies in Qualitative Organic Analysis. Identification of Alkyl Halides, Amines, and Acids.*

By (Miss) Ena L. Brown and Neil Campbell.

Methods for the identification and detection of certain classes of compounds are given. Alkyl bromides and iodides are identified as *S*-alkyl*iso*thioureas; aliphatic amines by means of 4-diphenylyl *iso*thiocyanate, β-naphthyl *iso*thiocyanate, and 2 : 4 : 5-trinitrotoluene; monobasic aliphatic acids as 2-alkylbenziminazole picrates. Alkyl nitrites are detected by means of 2-phenylindole.

An improved method for the preparation of 2 : 4-dinitrobenzoic acid is given.

In this work the reagents yielding derivatives suitable for the identification of certain classes of organic compounds can be readily prepared in the laboratory or purchased at small cost, and the derivatives are easily obtained and purified.

The methods used for the identification of the alkyl halides are often tedious. For example, their identification by means of potassium 3-nitrophthalimide (Sah and Ma, *Ber.*, 1932, **65**, 1630) requires ten hours' heating. The conversion of alkyl halides into alkyl mercuric halides (Marvel, Gauerke, and Hill, *J. Amer. Chem. Soc.*, 1925, **47**, 3009) by means of the Grignard reaction is much more satisfactory, but has the drawback that it can be used only with the primary alkyl halides, and the preparation of the Grignard reagent does not always proceed smoothly. We have found that thiourea is a suitable reagent for the identification of the alkyl bromides and iodides. *S*-Alkyl*iso*thioureas are formed and these yield picrates whose melting points are sharp. Their crystalline structure is also characteristic (for photomicrographs, see Brown, Thesis, Edinburgh, 1937). By this method compounds can be identified in a few minutes, but the method has the disadvantage that it is not applicable to alkyl chlorides or to tertiary compounds. Phenylthiourea is much less satisfactory than thiourea, as it reacts only with the straight-chain compounds.

Phenyl *iso*thiocyanate is often used for the identification of amines, but in the case of some aliphatic amines the thioureas have low melting points and are difficult to crystallise. We therefore tried other *iso*thiocyanates. 4-Diphenylyl *iso*thiocyanate proved to be very satisfactory, the resulting thioureas separating quickly. Their melting points are convenient and sharp. β-Naphthyl *iso*thiocyanate also gave good results. Suter and Moffett (*J. Amer. Chem. Soc.*, 1933, **55**, 2497) found α-naphthyl *iso*thiocyanate to be satisfactory. We also found *p*-tolyl *iso*thiocyanate, used by Whitmore and Otterbacher (*J. Amer. Chem. Soc.*, 1929, **51**, 1909) for aromatic amines, and *p*-chlorophenyl *iso*thiocyanate to be useful reagents, but *m*-nitrophenyl *iso*thiocyanate, used by Sah and Lei (*Centr.*, 1934, 3015) for aromatic amines, frequently yielded oily products with the aliphatic amines (for detailed results with the last three reagents, see Brown, *loc. cit.*).

Barger and Tutin (*Biochem. J.*, 1918, **12**, 402) used 2 : 4 : 5-trinitrotoluene as a reagent for amino-acids, the 5-nitro-group being replaced. The reagent was found to be excellent for the identification of small quantities of certain amines, a 10% alcoholic solution yielding instantly a clean precipitate of the substituted alkylaniline. The use of the reagent is, however, limited, as it reacts only with the primary amines, and in the case of the higher amines gives oily products.

Monobasic aliphatic acids react with *o*-phenylenediamine to form 2-substituted benziminazoles, and this method has been used for their identification (Seka and Muller, *Monatsh.*, 1931, **57**, 97). The method is not completely satisfactory, as it requires considerable time, and the melting points of many of the substituted benziminazoles lie close together. We have used the method of Phillips (J., 1928, 2393) and have formed the 2-alkylbenziminazole picrates, which have convenient melting points. While the work was in progress Pool, Harwood, and Ralston (*J. Amer. Chem. Soc.*, 1937, **59**, 178) reported the use of the 2-alkylbenziminazoles for identifying monobasic acids, and indicated that they may examine salts such as the picrates. We have therefore discontinued the work, and merely report what we have already accomplished.

Alkyl nitrites quickly form 3-oximino-2-phenylindole when treated with 2-phenylindole. This is a good method for detecting small quantities of nitrite, a 1% alcoholic solution yielding a precipitate without any difficulty. Attempts to apply the method quantitatively have so far met with little success, but the matter is being further investigated.

2 : 4-Dinitrobenzoic acid can be used for the identification of amines [Buehler and Calfee, *Ind. Eng. Chem.* (*Anal.*), 1934, 6, 351]. We have obtained a more suitable method for the preparation of this acid than that used by Curtius and Bollenbach (*J. pr. Chem.*, 1907, **76**, 288).

Experimental.

The m. p.'s recorded were all obtained with a thermometer standardised with pure compounds of known m. p. Most of the nitrogen analyses were obtained by the semi-micro Dumas method, but a few were done by Dr. Weiler, Oxford.

Preparation of S-*Alkyl*iso*thiourea Picrates.*—Finely powdered thiourea (0·2 g.) and an equal quantity of alkyl bromide or iodide were heated with alcohol (2 c.c.) for 2 minutes. Picric acid (0·2 g.), dissolved in the minimum quantity of boiling alcohol, was then added; on cooling, the picrate separated. It was crystallised from alcohol until a constant sharp m. p. was obtained.

S-*Alkyl*iso*thiourea picrates.*

Alkyl halide.	Formula.	M. p.	% N found.	% N calc.	Alkyl halide.	Formula.	M. p.	% N found.	% N calc.
Methyl	—	224°	—	—	*iso*Amyl	$C_{12}H_{17}O_7N_5S$	179°	18·8	18·7
Ethyl........	—	188	—	—	*sec.*-Amyl......	,,	143	18·9	,,
n-Propyl ...	$C_{10}H_{13}O_7N_5S$	181	20·6	20·2	*n*-Hexyl	$C_{13}H_{19}O_7N_5S$	157	18·3	18·0
*iso*Propyl ...	,,	148	20·4	,,	*Ethylene* dibromide ...	$C_{10}H_{13}O_7N_7S_2$	270	23·9	24·1
n-Butyl ...	$C_{11}H_{15}O_7N_5S$	180	19·7	19·4	Allyl	—	155	—	—
*iso*Butyl ...	,,	174	19·7	,,	Benzyl.........	$C_{14}H_{13}O_7N_5S$	188	17·6	17·7
sec.-Butyl...	,,	190	19·5	,,					
n-Amyl......	$C_{12}H_{17}O_7N_5S$	154	18·8	18·7					

The picrates were obtained in yellow needles or prisms. Benzyl chloride also can be identified by this method.

Thiocarbanilides.—The thiocarbanilides necessary for the preparation of the *iso*thiocyanates were prepared by Fry's method (*J. Amer. Chem. Soc.*, 1913, **35**, 1544). pp'-*Diphenylthiocarbanilide* was purified by boiling the crude product with alcohol and separating the white amorphous residue, m. p. 233—235° (Found: C, 78·8; H, 5·6; N, 7·4. $C_{25}H_{20}N_2S$ requires C, 78·9; H, 5·3; N, 7·3%).

	4-*Diphenylylthioureas.*				β-*Naphthylthioureas.*			
Amine.	Formula.	M. p.	% N found.	% N calc.	Formula.	M. p.	% N found.	% N calc.
Methyl	$C_{14}H_{14}N_2S$	142°	11·6	11·6	$C_{12}H_{12}N_2S$	127°	12·8	13·0
Ethyl	$C_{15}H_{16}N_2S$	165	10·9	10·9	$C_{13}H_{14}N_2S$	142	12·2	12·2
n-Propyl	$C_{16}H_{18}N_2S$	156	10·2	10·4	$C_{14}H_{16}N_2S$	114	11·5	11·5
n-Butyl	$C_{17}H_{20}N_2S$	155	9·8	9·9	$C_{15}H_{18}N_2S$	119	11·2	10·9
*iso*Butyl	,,	157	10·0	,,	,,	137	11·2	,,
n-Amyl	$C_{18}H_{22}N_2S$	147	9·3	9·4	$C_{16}H_{20}N_2S$	114	10·6	10·3
*iso*Amyl	,,	130	9·6	,,	,,	116	10·1	,,
n-Heptyl	$C_{20}H_{26}N_2S$	149	8·7	8·6	$C_{18}H_{24}N_2S$	115	9·7	9·3
Dimethyl	$C_{15}H_{16}N_2S$	225	11·3	10·9	$C_{13}H_{14}N_2S$	173	12·2	11·4
Diethyl	$C_{17}H_{20}N_2S$	114	9·8	9·9	$C_{15}H_{18}N_2S$	90	10·7	10·9
Dipropyl	$C_{19}H_{24}N_2S$	117	8·9	9·0	$C_{17}H_{22}N_2S$	109	9·9	9·8
Di*iso*butyl	$C_{21}H_{28}N_2S$	160	8·5	8·5	$C_{19}H_{26}N_2S$	136	9·2	8·9
Di-*n*-amyl	$C_{23}H_{32}N_2S$	118	7·7	7·6	$C_{21}H_{30}N_2S$	126	6·6	6·5
Benzyl	$C_{20}H_{18}N_2S$	147	9·0	8·8	$C_{18}H_{16}N_2S$	173	9·7	9·6
*cyclo*Hexyl	$C_{19}H_{22}N_2S$	180	9·3	9·0	$C_{17}H_{20}N_2S$	172	10·1	9·9
Bornyl	$C_{23}H_{28}N_2S$	167	7·8	7·7	—	—	—	—
Camphyl	$C_{23}H_{28}N_2S$	138	7·6	7·7	$C_{21}H_{24}N_2S$	127	8·3	8·6
Ethylenediamine	$C_{28}H_{26}N_4S_2$	237	15·3	15·5	$C_{24}H_{22}N_4S_2$	223	17·4	17·1

iso*Thiocyanates.*—These are best prepared by Steudemann's method (*Ber.*, 1883, **16**, 549, 2334). 4-*Diphenylyl* iso*thiocyanate* formed light brown needles from glacial acetic acid and on recrystallisation from alcohol was obtained in colourless needles, m. p. 70° (Found: C, 73·4; H, 4·6; N, 6·7; S, 14·2. $C_{13}H_9NS$ requires C, 73·9; H, 4·3; N, 6·6; S, 15·2%).

Preparation of Thioureas.—The amine (0·2 g.) and the *iso*thiocyanate (0·2 g.) were heated together for about 20 seconds, and 50% alcohol (2 c.c.) added. The thiourea deposited on cooling was recrystallised from 50% alcohol (table on p. 1700).

Preparation of 4 : 6-*Dinitro*-N-*alkyl*-m-*toluidines*.—2 : 4 : 6-Trinitrotoluene (0·1 g.) was dissolved in alcohol (1 c.c.), and 3 or 4 drops of the amine added. The compound separated immediately, and on crystallisation from alcohol yielded yellow or orange needles.

4 : 6-*Dinitro*-N-*alkyl*-m-*toluidines*.

Amine.	Formula.	M. p.	% N found.	% N calc.	Amine.	Formula.	M. p.	% N found.	% N calc.
Methyl	—	173°	—	—	*n*-Heptyl	$C_{14}H_{21}O_4N_3$	60°	14·4	14·2
Ethyl	$C_9H_{11}O_4N_3$	126	18·7	18·7	Ethylenediamine	$C_{16}H_{16}O_8N_6$	280	20·2	20·0
n-Propyl	$C_{10}H_{13}O_4N_3$	101	17·4	17·6	Benzyl	$C_{14}H_{13}O_4N_3$	100	14·4	14·6
n-Butyl	$C_{11}H_{15}O_4N_3$	96	16·6	16·6	Dipropyl	—	Oil	—	—
*iso*Butyl	,,	112	,,	,,	Diamyl	—	Oil	—	—
n-Amyl	$C_{12}H_{17}O_4N_3$	99	15·4	15·7					
*iso*Amyl	$C_{12}H_{17}O_4N_3$	87	15·6	,,					

Preparation of 2-Alkylbenziminazole Picrates.—*o*-Phenylenediamine (0·5 g.), the organic acid (0·5—1 g.), and 4N-hydrochloric acid (4 c.c.) were refluxed for 15 minutes. The solution was cooled, and aqueous ammonia added until the alkylbenziminazole separated. It was washed with water, dissolved in the minimum quantity of boiling alcohol, and added to a solution of picric acid (0·5 g.) in the minimum quantity of boiling alcohol. The picrate separated on cooling and was recrystallised from alcohol.

2-*Alkylbenziminazole picrates*.

Acid.	Formula.	M. p.	% N found.	% N calc.	Acid.	Formula.	M. p.	% N found.	% N calc.
Formic	—	230°	—	—	Hexoic	$C_{18}H_{19}O_7N_5$	282°	16·6	16·8
Acetic	$C_{14}H_{11}O_7N_5$	214	19·6	19·4	Lactic	$C_{15}H_{13}O_8N_5$	131	17·8	17·9
Propionic	$C_{15}H_{13}O_7N_5$	120	18·6	18·7	Glycollic	$C_{14}H_{11}O_8N_5$	214	18·5	18·6
Butyric	$C_{16}H_{15}O_7N_5$	124	18·1	18·0	Mandelic	$C_{20}H_{15}O_8N_5$	209	15·2	15·5
*iso*Butyric ...	,,	136	17·8	,,					

o-Phenylenediamine picrate prepared in the usual way was obtained in yellow needles, m. p 208° (decomp.) (Found: N, 25·4. Calc. for $C_{12}H_{11}O_7N_5$: N, 25·9%).

3-*Oximino-2-phenylindole.*—2-Phenylindole (0·1 g.) was dissolved in boiling alcohol, and the alkyl nitrite (0·1 g.) added. The oximino-compound separated on cooling and crystallised from amyl acetate in orange diamond-shaped needles, m. p. 280° (decomp.).

2 : 4-*Dinitrobenzoic Acid.*—Fuming nitric acid (500 c.c.) was added slowly to phenylacetic acid (50 g.), the mixture being cooled with running water. The solution was then refluxed for 1 hour and poured into water. The precipitate was washed with cold water. 2 : 4-Dinitrobenzoic acid (55 g., 70%) thus obtained was nearly pure, m. p. 180—182°. When recrystallised from water (4 parts) and alcohol (1 part), it was obtained in colourless needles, m. p. 181—182° (lit., 182—183°): yield, 45 g.

Thanks are expressed to the Carnegie Trust for the Universities of Scotland for the award of a Teaching Fellowship to one of the authors (N. C.).

University of Edinburgh. [*Received, September 4th, 1937.*]

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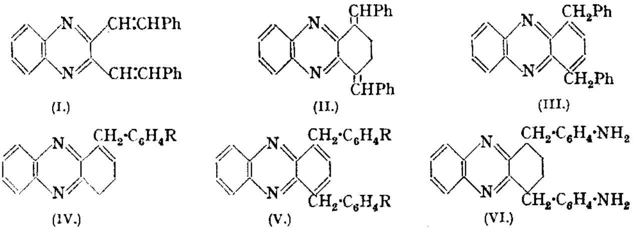
358. *The Phenazine Series. Part V. Reactions of* 1 : 2 : 3 : 4-*Tetrahydrophenazine and Related Compounds.*

By Henry McIlwain.

1- and 1 : 4-Substituted phenazine derivatives can be prepared from 1 : 2 : 3 : 4-tetrahydrophenazine by condensation with aromatic aldehydes. The methiodides of the tetrahydrophenazine and of *s*-octahydrophenazine do not undergo the varied ionic attack which takes place in phenazonium compounds (see following paper), but in

common with other pyrazine salts containing suitable saturated 1-substituents are decomposed by alkalis with the production of unsaturated bases.

Benzaldehyde and 1 : 2 : 3 : 4-tetrahydrophenazine react on heating with the production *of a compound* $C_{26}H_{20}N_2$, *which is considered to have the structure* (III) rather than (II) [compare the production of the distyrylquinoxaline (I) by Bennett and Willis, J., 1928, 1960] on account of its resistance to oxidation and dehydrogenation. *p*-Nitrobenzaldehyde



(I.) (II.) (III.)

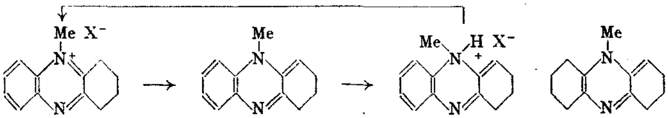
(IV.) (V.) (VI.)

also reacts with the tetrahydrophenazine, in acetic anhydride solution, with the production of 1-p-*nitrobenzyl*-3 : 4-*dihydrophenazine* (IV, R = NO_2) and 1 : 4-*bis*-p-*nitrobenzylphenazine* (V, R = NO_2), separable by the greater basicity and solubility of the former compound.

1-Aminophenazine derivatives may be of pharmacological interest (compare the acridine series; Mauss and Mietzsch, *Klin. Woch.*, 1933, 12, 1276), and it was attempted to prepare such compounds by these methods; direct condensation did not, however, take place between 1 : 2 : 3 : 4-tetrahydrophenazine and *p*-nitrosodimethylaniline, and 1 : 2 : 3 : 4-tetrahydrophenazine methiodide decomposed during the reaction. Production of an amine from the bis-*p*-nitrobenzylphenazine (V, R = NO_2) was accompanied by reduction of the nucleus, yielding 1 : 4-*bis*-p-*aminobenzyl*-1 : 2 : 3 : 4-*tetrahydrophenazine* (VI), but aminobenzylphenazines were prepared by condensation of *p*-dimethylaminobenzaldehyde with tetrahydrophenazine: refluxing in acetic anhydride solution produced 1-p-*dimethylaminobenzyl*-3 : 4-*dihydrophenazine* (IV, R = NMe_2) or 1 : 4-*bis*-p-*dimethylaminobenzylphenazine* (V, R = NMe_2) according to the proportions of reactants and the time of heating.

All the dibenzylphenazines prepared were slightly soluble in the commoner organic solvents, forming yellow fluorescent solutions, and yielded addition compounds with ferric chloride in glacial acetic acid.

The ready decomposition of 1 : 2 : 3 : 4-tetrahydrophenazine methiodide, which occurred with loss of halogen, led to an investigation of the action of alkali on the salt. The product of this reaction was a yellow oil, soluble in ether and benzene, which distilled unchanged under reduced pressure. This was clearly not the ammonium hydroxide and analysis



(VII.) (VIII.) (IX.) (X.)

indicated that it was not a *ψ*-base, but was produced from the hydroxide by loss of water. 1 : 2 : 3 : 4 : 5 : 6 : 7 : 8-*Octahydrophenazine methiodide* similarly produced a dehydro-base, obtained as a yellow oil, b. p. 160°/1 mm. The absence of an analogous reaction in pyrazine methiodide indicates that the change involves one of the hydrogen atoms of the reduced phenazine nucleus, and it is suggested that it follows the course indicated in (VIII) and (X).

The action of acids on the N-*methyltetrahydrophenazine* (VIII) produced first an unstable

red salt, which changed spontaneously in the course of a few minutes to a normal yellow tetrahydrophenazonium salt; this is presumably the isomerisation (IX) to (VII) in the above scheme. The N-*methyloctahydrophenazine* (X) reacts in the same way, and these changes are also paralleled by those investigated in the methylpyrazines by Gastaldi (*Gazzetta*, 1929, **59**, 751) and by Aston (*J. Amer. Chem. Soc.*, 1931, **53**, 1448). The dehydro-bases were also the only isolable products from the action of sodium cyanide, sulphite, and sulphide on the methiodides of the tetrahydro- and octahydro-phenazines.

Experimental.

1 : 4-*Dibenzylphenazine*.—1 : 2 : 3 : 4-Tetrahydrophenazine (J., 1934, 1991) (3 g.) and freshly distilled benzaldehyde (4 g.) were heated at 200° for 30 minutes; water was evolved during the first 10 minutes and, on cooling, the material set to a resin, which crystallised from alcohol or benzene–alcohol (1 : 2) in sulphur-yellow needles, m. p. 158° (Found: C, 87·1; H, 5·8. $C_{26}H_{20}N_2$ requires C, 86·7; H, 5·6%). The compound was not dehydrogenated by the action of iodine in glacial acetic acid, potassium ferricyanide, or by sulphur and selenium in xylene. Ferric chloride in glacial acetic acid produced a solvated *ferrichloride*, crystallising in large blood-red prisms, m. p. 200° (Found: C, 57·6; H, 4·1; residue, 13·4. $C_{26}H_{20}N_2,FeCl_3,C_2H_4O_2$ requires C, 57·7; H, 4·1; residue, 13·7%); its solutions in acetic acid were deep red, but in alcohol and ether were yellow, and from them, on concentration, 1 : 4-*dibenzylphenazine* separated. The salt also decomposed in water.

1-p-*Nitrobenzyl*-3 : 4-*dihydrophenazine and* 1 : 4-*Bis*-p-*nitrobenzylphenazine*.—1 : 2 : 3 : 4-Tetrahydrophenazine (1·8 g.), *p*-nitrobenzaldehyde (3·5 g.), and acetic anhydride (15 c.c.) were refluxed for 40 minutes; a bulky precipitate separated before or during cooling, and was filtered off immediately, washed with alcohol, and recrystallised from benzene or chloroform. It formed yellow plates (2·4 g.), m. p. 250°, whose analysis (Found: C, 69·7; H, 4·1. $C_{26}H_{18}O_4N_4$ requires C, 69·4; H, 4·0%) indicated it to be the 1 : 4-*bis*-p-*nitrobenzyl* compound.

From the acetic acid mother-liquors, after 24 hours, a material (0·9 g.) separated, which crystallised from alcohol in yellow prisms, m. p. 172°, and analysis (Found: C, 72·1; H, 5·0. $C_{19}H_{15}O_2N_3$ requires C, 71·9; H, 4·7%) showed it to be the product of an equimolecular condensation. It differed from the dibenzyl compound in forming a rich red solution in concentrated hydrochloric acid (that of the dibenzyl compound is yellow) and in being soluble in dilute acids.

1 : 4-*Bis*-p-*aminobenzyl*-1 : 2 : 3 : 4-*tetrahydrophenazine*.—The preceding dinitro-compound (0·4 g.), concentrated hydrochloric acid (20 c.c.), and stannous chloride (10 g.) were warmed at 100° for 2 hours; the initially red solution became green and then red again. Water was added, the solution basified (sodium hydroxide) and extracted with ether, the extract dried, the solvent removed, and the residue crystallised from alcohol, yielding colourless plates, m. p. 176° (Found: C, 78·9; H, 6·8. $C_{26}H_{26}N_4$ requires C, 79·2; H, 6·6%). It yielded a diazonium compound, but gave no coloration with ferric chloride (*i.e.*, is not reduced in the *NN'*-positions). Titanous chloride or hydrogen sulphide did not reduce the original dinitro-compound.

1-p-*Dimethylaminobenzyl*-3 : 4-*dihydrophenazine*.—1 : 2 : 3 : 4-Tetrahydrophenazine (1·0 g.), *p*-dimethylaminobenzaldehyde (1·6 g.), and acetic anhydride (10 c.c.) were refluxed for 40 minutes, the solution was warmed with water to decompose the anhydride, basified (sodium hydroxide), and extracted with ether, the extract dried, the solvent removed, and the residue crystallised from methyl alcohol and recrystallised from benzene, yielding yellow prisms of the equimolecular condensation *product* (0·5 g.), m. p. 158° (Found: C, 80·2; H, 6·9. $C_{21}H_{21}N_3$ requires C, 80·0; H, 6·7%).

1 : 4-*Bis*-p-*dimethylaminobenzylphenazine*.—The tetrahydrophenazine (0·5 g.), *p*-dimethylaminobenzaldehyde (2·0 g.), and acetic anhydride (10 c.c.) were refluxed for 6 hours; the product, separated as described above, crystallised from benzene in bright cinnabar-red prisms (0·2 g.), m. p. 207°, of the *bis*-p-*dimethylaminobenzyl* compound (Found: C, 80·5; H, 6·7. $C_{30}H_{30}N_4$ requires C, 80·7; H, 6·7%).

1 : 2 : 3 : 4-*Tetrahydrophenazine Monomethiodide*.—The base (4 g.) and methyl iodide (4 g.) were heated in a sealed tube at 100° for 2 hours, and the product washed with ether and crystallised from aqueous alcohol (6·4 g., m. p. 207°) (Found: I, 39·2. $C_{13}H_{15}N_2I$ requires I, 39·0%).

9-*Methyl*-2 : 3 : 4 : 9-*tetrahydrophenazine*.—An aqueous solution of 1 : 2 : 3 : 4-tetrahydrophenazine methiodide was basified (sodium hydroxide) and extracted with ether, and the extract concentrated and distilled in a vacuum, yielding the *base* as a viscous, golden-yellow oil, b. p. 170°/1 mm. (Found: C, 78·5; H, 7·2. $C_{13}H_{14}N_2$ requires C, 78·8; H, 7·1%). Qualitative tests indicated the base to be unchanged by distillation; it was volatile in steam and yielded

indefinite salts with picric acid. In the air, the base was converted after a few days into a red tar; oxidising agents caused this change immediately. The base yielded phenazine (20%) when dehydrogenated with palladium-charcoal at 200°.

1 : 2 : 3 : 4 : 5 : 6 : 7 : 8-*Octahydrophenazine Methiodide*.—The octahydro-compound (1·0 g.), freshly distilled methyl iodide (2·0 g.), and methyl alcohol (1·0 c.c.) were heated in a sealed tube at 100° for 6 hours; the *product* crystallised from water in yellow prisms, m. p. 175° (Found: I, 38·3. $C_{12}H_{16}N_2$,MeI requires I, 38·5%). The green-violet compound described by Godchot (*Compt. rend.*, 1925, **180**, 444) as *s*-octahydrophenazine methiodide must be regarded as impure.

9-*Methyl*-2 : 3 : 4 : 5 : 6 : 7 : 8 : 9-*octahydrophenazine*.—The above methiodide (2 g.) was dissolved in water (20 c.c.), sodium hydroxide solution added in excess, the mixture extracted with ether, and the extract dried; the *product* distilled under reduced pressure (b. p. 160°/1 mm.) as an orange-yellow oil (1 g.) (Found: C, 77·3; H, 8·9. $C_{13}H_{18}N_2$ requires C, 77·2; H, 8·9%), which rapidly turned red in air.

I wish to acknowledge my indebtedness to Professor G. R. Clemo for advice received, to Mr. O. Telfer for microanalyses, and to the Department of Scientific and Industrial Research for a maintenance grant and research award.

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Dyson Perrins Laboratory, Oxford University. [*Received, September 7th, 1937.*]

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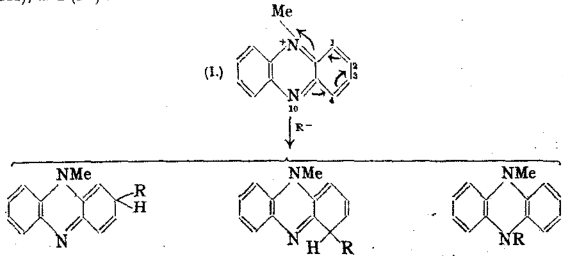
359. *The Phenazine Series. Part VI. Reactions of Alkyl Phenazonium Salts; the Phenazyls.*

By Henry McIlwain.

The biological interest attached to pyocyanine (Friedheim, *Biochem. J.*, 1934, **28**, 173) and to *N*-methylphenazonium salts (Dickens, *ibid.*, 1936, **30**, 1064, 1233) suggested an investigation of the reactions of the latter compounds, and a number of keto-derivatives, sulphonic acids, and cyanides have been prepared by ionic attack of the phenazonium nucleus. Phenazonium salts differ markedly from compounds previously investigated (*e.g.*, quinolinium, acridinium salts) in the decomposition of the quaternary methohydroxide, and in the effect of visible radiation in the production of a keto-compound. Examples of free radicals in the phenazine series, which it is proposed to term *phenazyls*, have been discovered; they represent the bases of the semiquinonoid salts recently studied by Michaelis (*Chem. Reviews*, 1935, **16**, 243).

Previously recorded instances of nuclear attack of phenazonium, phenazoxonium, and phenazthionium salts have been confined to the action of oxidising agents, alone or in the presence of bases, which have invariably caused substitution in the 2-position. Under various conditions, facile substitution has now been observed in the 2-, 4-, and 10 (*N'*)-positions of phenazonium salts, which suggests that the molecule can be activated according to the mechanism indicated in (I) and that the primary products are the dihydro-derivatives (II), (III), and (IV):



(II.) (III.) (IV.)

Kehrmann (*Ber.*, 1913, **46**, 341) demonstrated that phenazine methosulphate reacted with ammonia in the presence of air with the production of 2-aminophenazine methosulphate, and suggested that with oxygen alone it yielded 2-keto-*N*-methylphenazine. This has now been proved by the isolation of the red product of oxidation and its comparison with the 2-keto-*N*-methylphenazine prepared by the later method of Kehrmann and Cherpillod (*Helv. Chim. Acta*, 1924, **7**, 973), though both specimens melted higher than is recorded by those authors. The yield varied with temperature, but was never greater than 5%, the bulk of the product being phenazine. Such oxidative demethylation has also been observed in naphthaphenazonium salts (Fischer, *Ber.*, 1893, **26**, 180) and in pyocyanine (Wrede and Strack, *Z. physiol. Chem.*, 1929, **181**, 68), and 2-hydroxyphenazine has now been obtained from 2-keto-*N*-methylphenazine under the conditions of the latter reaction.

N-Methylphenazonium hydroxide, presumably the immediate product of the reaction between *N*-methylphenazonium salts and alkalis, was found to be unstable even in the absence of air; in aqueous solution, a precipitate of phenazine and *N*-methyldihydrophenazine was formed, and formaldehyde detected. Quantitative experiments showed the reaction to follow the equation

$$2C_{13}H_{11}N_2{\cdot}OH \longrightarrow C_{13}H_{12}N_2 + C_{12}H_8N_2 + CH_2O + H_2O$$

which is closely analogous to the decomposition of methoxytrimethylammonium iodide observed by Dunstan and Goulding (J., 1899, **75**, 797)

$$OMe{\cdot}NMe_3I \longrightarrow NHMe_3I + CH_2O$$

and of methoxyphenyldimethylammonium iodide to dimethylaniline hydriodide and formaldehyde (Bamberger and Tschirner, *Ber.*, 1899, **32**, 1882). It is suggested that the complete decomposition of the phenazonium salt to dihydrophenazine and formaldehyde does not occur owing to part of the salt acting as hydrogen acceptor and forming equivalent amounts of phenazine and *N*-methyldihydrophenazine. This decomposition prevents the formation of pure methylphenazonium salts through the hydroxide (compare Browning, Cohen, and coll., *Proc. Roy. Soc.*, 1922, *B*, **93**, 329). The small amount of 2-keto-*N*-methylphenazine produced by alkaline oxidation of phenazonium salts is probably derived from the *N*-methyldihydrophenazine, which was observed to produce phenazine and a little 2-keto-*N*-methylphenazine on oxidation. Formaldehyde was also detected in the products of anaerobic alkaline decomposition of the two keto-*N*-methylphenazines.

Under the influence of visible light, oxidation of *N*-methylphenazonium salts occurred more rapidly and produced mainly the 4-keto-compound, pyocyanine, in much greater yield (45 mol. %), together with phenazine (47 mol. %) and small amounts of 1-hydroxyphenazine and 2-keto-*N*-methylphenazine. The reaction proceeded in this manner in acidic, neutral, or slightly alkaline aqueous solutions, but did not take place in alcohol or chloroform. It is probable that the 2-keto-*N*-methylphenazine produced in this reaction is formed by the normal dark reaction, and the 1-hydroxyphenazine by demethylation of pyocyanine. Photochemical reactions possibly analogous to that described above have been recorded in the production of quinhydrone from quinol (Hartley and Little, J., 1911, **99**, 1079) and in the isomerisation of tris-*p*-aminophenylacetonitrile (Liftschitz and Joffe, *Z. physikal. Chem.*, 1921, **97**, 426). The present synthesis of pyocyanine is much simpler than the original method of Wrede and Strack (*Z. physiol. Chem.*, 1928, **177**, 184; 1929, **181**, 58). As the introduction of a nuclear keto-group is a reaction which occurs biologically, the production of pyocyanine from *N*-methylphenazonium salts may constitute a biosynthesis. Light is not necessary for the pigmentation of *B. pyocyaneus*, but it was considered possible that the production of pyocyanine might be an enzyme reaction, and the action of tyrosinase on methylphenazonium salts was accordingly investigated; no action took place over the range of p_H within which the enzyme is active.

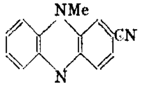
Phenazine ethosulphate, prepared by direct addition of ethyl sulphate at 150°, does not lose its alkyl group with the facility of the *N*-methyl compound, but is comparable with the *N*-phenyl derivatives in stability and, like those compounds, forms a 2-ketophenazine in excellent yield by oxidation in alkaline solution. Photochemical oxidation of the etho-

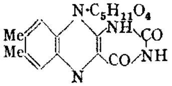
sulphate yields 4-keto-*N*-ethylphenazine; phenazine is not produced as a by-product, and neither of the keto-*N*-ethyl compounds undergoes ready dealkylation.

The reaction of phenazine methosulphate with sodium cyanide proceeded slowly in dilute aqueous solution and yielded mainly phenazine. In more concentrated solution, N-*methyldihydrophenazine-2-nitrile* was isolated in 60% yield. This was demethylated on heating with the production of a phenazine nitrile which yielded phenazine-2-carboxylic acid on hydrolysis; these reactions do not prove the relative positions of the Me and the CN group in the original compound, which are assumed from the mechanism of the reaction and from analogous instances to be as indicated in (II).

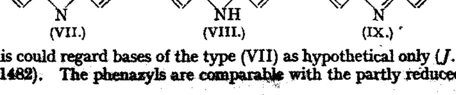
As a by-product in the preparation of *N*-methyldihydrophenazine-2-nitrile, a less soluble, dark blue compound was separated whose analysis indicated the formula $C_{14}H_{10}N_3$. This differs from that of the dihydrophenazine derivative in having one less hydrogen atom, and the by-product is converted into the dihydro-compound on reduction; the reverse reaction was performed by oxidation under a variety of conditions (air in markedly acid or alkaline solution; lead peroxide in ether; nitrous acid). The state of oxidation of the phenazine nucleus in the two compounds was also shown quantitatively by titration with iodine in acid solution, a process first applied to the phenazine series by Wohl (*Ber.*, 1903, **36**, 4135); the dihydro-compound required two equivalents of iodine in oxidation to the holoquinonoid salt, and the blue compound, whose acid solutions were of the green colour characteristic of semiquinones in the phenazine series (Michaelis, *loc. cit.*) required, like those compounds, one equivalent of iodine per phenazine nucleus.

Unlike that of the phenazine–dihydrophenazine complexes which represent an intermediate stage in the oxidation of non-alkylated phenazine compounds, the colour of the blue nitrile, which closely resembles that of the simpler phenazhydrins, persists in its solutions (compare Clemo and McIlwain, J., 1934, 1991). The molecular size can therefore be determined by measurement of molecular weight, and such values, determined ebullioscopically in chloroform, definitely indicated the C_{14} formula. The compound must therefore possess an atom of unusual valency, probably, by analogy with the diphenyls of Wieland, the non-alkylated nitrogen atom, as is represented in (V), and the name N-*methylphenazyl-2-nitrile* is suggested. It would appear likely that one condition for the formation of stable free radicals in such compounds is the possession of a nitrogen substituent which, not having the mobility of a hydrogen atom, does not permit of the dismutation which takes place in the phenazhydrins on solution.

(V.) 

 (VI.)

Qualitative evidence was obtained for the production of a phenazyl on oxidation of *N*-methyldihydrophenazine in non-aqueous solutions, which rapidly became red in air; but it was not possible to isolate the compound in a pure condition owing to its decomposition with formation of phenazine. The *N*-ethyl compound was, however, stabler in this respect, and a dark purple N-*ethylphenazyl* was prepared by oxidation of N-*ethyldihydrophenazine* (obtained by reduction of *phenazine ethosulphate*) in ethereal or in benzene solution. It possessed the iodine equivalent and molecular weight corresponding to $C_{14}H_{13}N_2$. The conversion of a phenazyl into a semiquinonoid salt (using Michaelis's representation of these compounds) and its subsequent oxidation can then be formulated:



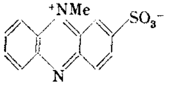
(VII.) (VIII.) (IX.)

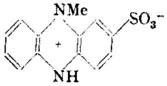
though Michaelis could regard bases of the type (VII) as hypothetical only (*J. Amer. Chem. Soc.*, 1933, **55**, 1482). The phenazyls are comparable with the partly reduced lactoflavine

(VI), established recently by Kuhn and Ströbele as a free radical (*Ber.*, 1937, 70, 753). Compounds described as nitrodihydrophenazines by Kehrmann and Messinger (*Ber.*, 1893, 26, 2374) and by Leemann and Grandmougin (*Ber.*, 1908, 41, 1309) possess properties unusual in dihydrophenazines but closely similar to those of the phenazyls here described, and the analytical figures of those authors are invariably in better agreement with the corresponding phenazyl.

The reaction of phenazine methosulphate with sodium sulphite produced a little *N*-methyldihydrophenazine, and a mixture of mono- and di-sulphonic acid, the former of which was separated by the lesser solubility of its sodium salt in water. This *sodium* N-*methyldihydrophenazinesulphonate* is assumed to be the 2-compound by analogy with the preceding reactions; it has not been found possible to obtain a derivative of known configuration from it. Heating with potassium hydroxide and cyanide in an attempt to obtain such a compound yielded only phenazine; demethylation was readily brought about by heat.

Sodium *N*-methyldihydrophenazinesulphonate is readily oxidised in solution, and the process was followed quantitatively by iodine titration. Complete oxidation with two equivalents yielded an *N*-methylphenazonium salt (X), crystallising from water in yellow needles; partial oxidation afforded a deep green compound, $C_{13}H_{11}O_3N_2S$, which possessed

(X.) 

 (XI.)

the properties of the internal semiquinonoid salt (XI) of *N*-methylphenazyl-2-sulphonic acid. The holoquinonoid sulphonic acid was susceptible to further substitution; sodium sulphite formed a labile dihydro-disulphonic acid; this was isolated as its semiquinonoid salt, and underwent quantitative oxidation to the holoquinonoid compound. Qualitative evidence was also obtained for attack by hydroxyl and cyanide ions. The dihydro-disulphonic acid is identical with the compound isolated from the initial reaction between phenazine methosulphate and sodium sulphite, which proceeds to completion only in the presence of excess of sulphite; both mono- and di-sulphonic acid are also formed during the reduction of the methosulphate with hyposulphite. The biological properties of these sulphonic acids, and of the keto-*N*-ethylphenazines, will be described elsewhere. Qualitative evidence has been obtained for the production of thiophenazones by the action of sodium sulphide on phenazine methosulphate and ethosulphate.

Substitution in the *N'*-position of the phenazonium nucleus was observed in the action of methylmagnesium iodide on phenazine methosulphate, which yielded *NN'*-dimethyldihydrophenazine; this affords a much more convenient method of preparation of this compound, which has been shown to possess biological action (Dickens, *Biochem. J.*, 1936, **30**, 1064), than was formerly available (Clemo and McIlwain, J., 1935, 738).

Experimental.

Oxidation of Phenazine Methosulphate.—The salt (2·0 g.) and sodium carbonate (0·3 g.) in water (50 c.c.) at room temperature were exposed to the air for 1 week; red crystals, consisting largely of phenazine, were deposited. The whole was evaporated to dryness, the residue extracted with the minimum amount of alcohol, twice the volume of water added, and the alcohol removed, leaving a precipitate of phenazine (1·0 g.), and in solution 2-keto-*N*-methylphenazine, which, recrystallised from water, formed deep red prisms (0·05 g., m. p. 200°; compare Kehrmann and Cherpillod, *loc. cit.*). Preliminary experiments were performed in which the yield of 2-keto-*N*-methylphenazine was estimated by colorimetric comparison with a solution of the product containing 1 mg./10 c.c.; these indicated that the yield was not increased by the addition of oxidising agents, and was appreciably decreased by carrying out the reaction at higher temperatures.

Oxidation of N-*Methyldihydrophenazine.*—The compound (1·0 g.) in alcohol (50 c.c.) was exposed to the air for 4 days; the solution became rich red, and after concentration was separated as described above into phenazine (0·8 g.) and 2-keto-*N*-methylphenazine (0·05 g.). Oxidation

with lead peroxide and with silver oxide afforded similar results. It was, however, observed that the first product of oxidation was blue-red, was extracted from its aqueous alcoholic solution by ether, and formed a green salt with acids; it is presumably *N*-methylphenazyl, and the above air oxidation, as in the case of the 2-nitrile, was accelerated by the presence of potassium hydroxide in the alcoholic solution.

Demethylation of 2-Keto-N-methylphenazine.—The keto-compound (0·1 g.) in sodium hydroxide solution (50 c.c. of 2%) with hydrogen peroxide (1 c.c. of 20 vol.), heated at 80° for 1 hour, lost its bright red and became a browner colour; while the solution was warm, acetic acid was added in excess, and after standing, the fine red precipitate of hydrated 2-hydroxyphenazine (0·06 g.) was collected; m. p. 254°, undepressed by a specimen prepared by Kehrmann's method.

Reaction of Phenazine Methosulphate with Alkali.—To the salt (0·100 g.; 0·000327 mol.) in water (20 c.c.) in a distilling flask through which a slow stream of oxygen-free nitrogen was passed, 10% sodium carbonate solution (10 c.c.) was added, and two-thirds of the liquid distilled into a little ice-cooled water. Decomposition took place on warming and some phenazine steam-distilled; more water was added to the flask, and the distillation repeated. The distillate was filtered, and formaldehyde estimated by the method of Bodea (*Bull. Soc. chim.*, 1930, **47**, 1408): 5 : 5-dimethyldihydroresorcinol solution (2 c.c. of 10% alcoholic) was added, the whole heated at 100° for 10 minutes, and kept for 2 hours. The precipitate was dried at 100° and weighed (0·045, 0·047 g., equiv. to 0·000154, 0·000162 mol.; m. p. 186°, undepressed by admixture with genuine formaldehyde-dimedon). Control experiments showed that 98% of a known amount of formaldehyde could be removed from aqueous solution and estimated in this way.

The residue in the distilling flask dissolved in dilute acid to a green solution, which was titrated immediately with N/50-iodine solution until the phenazine compounds had been oxidised to their yellow holoquinonoid salts (16·3, 16·0 c.c.; 0·000326, 0·000320 mol.). Starch was used as external indicator, and the end-point could also be judged by the appearance of an opalescence due to excess of iodine forming insoluble periodides. The presence of methylphenazonium salts in the oxidised solution was established in a reaction performed on a larger scale by the isolation of the slightly soluble iodide (m. p. 169°). Similar quantitative results were obtained in the reaction between phenazonium salts and sodium acetate; but the amount of formaldehyde isolated when the decomposition was affected by means of sodium hydroxide was smaller, presumably owing to its polymerisation by the alkali.

Pyocyanine was decomposed by sodium carbonate, and 2-keto-*N*-methylphenazine by sodium hydroxide, again with the production of formaldehyde and reduced compounds, but the reactions did not proceed quantitatively.

Photochemical Oxidation of Phenazine Methosulphate.—The salt (2·0 g.) in water (2 l.) was exposed to sunlight in an open flask until no further change took place, as was judged by colorimetric comparisons of portions of the reacting solution, made alkaline by addition of sodium carbonate, with a standard solution of pyocyanine (1 mg./10 c.c.). This occurred after about 50% of the theoretical amount of pyocyanine had been formed, and in the course of about 1 day. 10% Sodium carbonate solution (40 c.c.) was added, the whole fully extracted with chloroform, and the extract dried with potassium carbonate and evaporated under reduced pressure to 20 c.c. Hot light petroleum was added, the solution allowed to cool, and the deep blue crystalline precipitate of pyocyanine (0·65 g.) collected and recrystallised from water. It was identified by its m. p. (133°) and by degradation (Wrede and Strack, *Z. physiol. Chem.*, 1928, **177**, 177) to 1-hydroxyphenazine (m. p. 154°, undepressed by admixture with an authentic specimen).

The petroleum mother-liquors were fully extracted with water, the extract concentrated to crystallisation under reduced pressure, and the product recrystallised from water, yielding red prisms, identified by m. p. and mixed m. p. (200°) as 2-keto-*N*-methylphenazine (0·05 g.). The washed petroleum solution was further extracted with dilute aqueous alkali, the extract acidified with acetic acid, and the yellow precipitate obtained dried and crystallised from alcohol, giving 1-hydroxyphenazine (0·05 g., m. p. 154°). The petroleum solution on evaporation to crystallisation now yielded phenazine (0·55 g., m. p. 171°).

When solutions of the phenazonium salt were exposed to light with the addition of oxidising agents (potassium ferricyanide or persulphate), these were reduced but the yield of pyocyanine was not altered.

Attempted Photochemical Oxidations.—Kehrmann's preparation of aminophenazine methosulphate (*loc. cit.*) could not be performed photochemically, as the reaction proceeded rapidly in concentrated solutions, and in dilute solutions it followed a different course, apparently

yielding *N*-methylphenazyl; phenazine was the only product isolated. The oxidation of pyridinium ("Organic Syntheses," 1935, 15, 41), quinolinium (J., 1913, 1977), and acridinium salts (*J. pr. Chem.*, 1892, 45, 193) did not proceed differently in sunlight.

Reaction of Phenazine Methosulphate with Cyanide.—Sodium cyanide (1·0 g.) in water (5 c.c.) was added gradually with shaking to a cooled suspension of finely powdered phenazine methosulphate (4·0 g.) in chloroform (15 c.c.). After ½ hour, the aqueous layer had become colourless and contained sodium methyl sulphate; blue crystals had formed in the chloroform layer and were filtered off, washed with chloroform, and recrystallised from that solvent, forming blue needles (0·35 g.), m. p. 145°, of N-*methylphenazyl-2-nitrile* (Found: C, 76·1; H, 4·5; iodine equiv., 224, 228; *M*, in chloroform, 227, 217. $C_{14}H_{10}N_3$ requires C, 76·4; H, 4·5%; iodine equiv. and *M*, 220). The compound forms blue-green solutions in organic solvents, and dissolves in dilute mineral acids to the emerald-green semiquinone, becoming colourless with zinc and yellow with persulphate.

The chloroform mother-liquors were combined, the solvent removed, the brown residue extracted repeatedly with hot benzene, and the solution concentrated, yielding bright yellow needles of N-*methyldihydrophenazine-2-nitrile* (1·7 g.). From the cooler solvent this compound separated in stout yellow-green prisms; both forms on drying at 100° fell to a yellow powder m. p. 155° (Found: C, 75·7; H, 4·8; iodine equiv., 113, 115. $C_{14}H_{11}N_3$ requires C, 76·0; H, 4·8%; iodine equiv., 110·5). The compound is soluble in dilute acids to yellow solutions, becoming first green and then bright yellow on oxidation.

The material not extracted by benzene could not be obtained in crystalline condition, but on sublimation under reduced pressure at 240° for 10 hours, phenazine (0·2 g.) and a little phenazine-2-nitrile were obtained. When the initial reaction was performed in more dilute aqueous solution, a much greater quantity of phenazine was produced.

Interconversion of the N-*Methyl Nitriles.*—(*a*) The dihydro-base (0·1 g.) in alcohol (10 c.c.) containing potassium hydroxide (0·2 g.) remained unchanged in an atmosphere of nitrogen, but in air darkened in colour, and blue crystals of *N*-methylphenazyl-2-nitrile separated (0·08 g., m. p. 145°).

(*b*) The dihydro-base (0·1 g.) in 10% hydrochloric acid (5 c.c.) dissolved to a yellow solution, which became deep green on standing in air for 1 hour; excess of sodium hydroxide produced a blue sludge, which was extracted with chloroform, the extract, dried (potassium carbonate) and concentrated to crystallisation, giving *N*-methylphenazyl-2-nitrile (0·07 g.).

(*c*) To the dihydro-base (0·1 g.) in alcohol (10 c.c.) were added sodium nitrite (0·05 g.) in water (2 c.c.), and sulphuric acid (2%) drop by drop with shaking, with the intention of preparing a nitroso-derivative. The phenazyl (0·08 g.) separated.

(*d*) *N-Methylphenazyl-2-nitrile (0·1 g.) in alcohol, sodium hydroxide (0·2 g.) in water (2 c.c.)*, and sodium hyposulphite (0·2 g.) in water (2 c.c.) were mixed in an atmosphere of nitrogen in a tap-funnel; the solution rapidly became yellow. An equal volume of chloroform was added, the aqueous layer separated, and the chloroform washed with water. When free from alkali it was no longer sensitive to air, and was dried (sodium sulphate), the solvent removed, and the residue crystallised from benzene, yielding *N*-methyldihydrophenazine-2-nitrile (0·07 g.).

Phenazine-2-carboxylic Acid.—Both of the *N*-methyl nitriles changed above 80° and a higher-melting compound slowly sublimed. Either compound (0·1 g.), heated in a loosely corked tube at 200° for 12 hours, gave a yellow sublimate (0·03 g.), crystallising from alcohol in fine sulphur-yellow needles, m. p. 226°. This compound (0·1 g.) in alcohol (10 c.c.) containing potassium hydroxide (1 g.) was refluxed for 2 hours; ammonia was evolved. An equal volume of water was added, the alcohol removed, the solution acidified, and the flocculent precipitate collected, dried, and crystallised from acetone, yielding yellow needles of phenazine-2-carboxylic acid (0·07 g.), m. p. 284°, not depressed by admixture with an authentic specimen.

Attempted demethylation of the original nitriles in better yield by refluxing in xylene, or under the alkaline peroxide conditions used for the keto-compounds, was not successful; the latter reaction produced a little phenazine-2-carboxylic acid.

Sodium N-*Methyldihydrophenazinesulphonate.*—Phenazine methosulphate (5 g.) in water (30 c.c.) and sodium sulphite (2·5 g.) in water (15 c.c.) were mixed with cooling; the yellow solution darkened to brown-red and became opalescent in the course of 1 minute; it was warmed slightly and kept for ½ hour; a bulky grey crystalline precipitate then separated. This was filtered off with minimum exposure to the air, washed free from inorganic matter with water and from *N*-methyldihydrophenazine with alcohol, followed by chloroform, recrystallised from water containing a little reducing agent ($NaHSO_3$), and dried in a vacuum at 20°, giving the hydrated *sodium* salt in colourless plates (1·7 g.) (Found: C, 49·0; H, 4·1; iodine equiv., 162,

$C_{13}H_{11}O_3N_2SNa,H_2O$ requires C, 49·3; H, 4·1%; iodine equiv., 158). On drying at a higher temperature, decomposition took place and the analytical figures approximated to those of the demethylated compound; on standing in air, the compound and its solutions became red.

From the chloroform portion of the washings, *N*-methyldihydrophenazine (0·6 g.) was isolated. The aqueous layer was evaporated under reduced pressure of nitrogen to 10 c.c.; *sodium N-methyldihydrophenazinesulphonate* (0·55 g.) then separated. The mother-liquors from this crystallisation had an intense greenish fluorescence due to the disulphonic acid, which was isolated as its internal semiquinonoid salt (1·85 g.) (see below).

N-*Methylphenazylsulphonic Acid Betaine.*—To a solution of sodium *N*-methyldihydrophenazinesulphonate (1·0 g.) in 10% sulphuric acid (10 c.c.), potassium persulphate (0·5 g. in the minimum quantity of water) was added; a green crystalline precipitate gradually formed. The solution was kept for 2 hours, and the *product* was then collected, recrystallised from water, and dried in a vacuum at 80° (0·7 g., not melting at 300°) (Found: C, 56·3; H, 4·2; iodine equiv., 276. $C_{13}H_{11}O_3N_2S$ requires C, 56·7; H, 4·0%; iodine equiv., 275).

N-*Methylphenazoniumsulphonic Acid Betaine.*—To the phenazylsulphonic acid (1·0 g.) in 10% sulphuric acid (10 c.c.), a saturated solution of potassium persulphate was added until the whole became a golden-yellow solution; this was concentrated to crystallisation, yielding yellow needles (0·8 g.) (Found: C, 56·75; H, 3·8. $C_{13}H_{10}O_3N_2S$ requires C, 56·9; H, 3·65%).

Sodium Hydrogen N-*Methylphenazyldisulphonate Betaine.*—To a solution of the above holoquinonoid salt (1·0 g.) in water (20 c.c.), sodium sulphite (0·5 g.) in water (5 c.c.) was added; the solution became orange-red with a green fluorescence, and an impure specimen of sodium *N*-methyldihydrophenazinedisulphonate was obtained by precipitation with alcohol and crystallisation from aqueous alcohol (Found: iodine equiv., 210. Calc. for $C_{13}H_{10}O_6N_2S_2Na_2$: iodine equiv., 200). The whole was converted into the readily crystallised semiquinone by the addition of 20% sulphuric acid (2 c.c.) and potassium persulphate (0·4 g.); deep green needles separated, and were recrystallised from water and dried in a vacuum at 100° (1·0 g.) (Found: C, 41·5; H, 2·7; iodine equiv., 385, 380. $C_{13}H_{10}O_6N_2S_2Na$ requires C, 41·4; H, 2·7%; iodine equiv., 377).

Phenazine Ethosulphate.—Phenazine (5·0 g.) and ethyl sulphate (7 c.c.) were heated at 150° until a test portion dissolved completely in water (40 minutes); the mixture was then cooled, and crystallised from alcohol, yielding the *salt* in brown prisms (8·5 g.), m. p. 190° (Found: C, 57·55; H, 5·6. $C_{12}H_8N_2,Et_2SO_4$ requires C, 57·4; H, 5·4%).

2-*Keto*-N-*ethylphenazine.*—To a solution of phenazine ethosulphate (1·0 g.) and potassium ferricyanide (2·0 g.) in water (40 c.c.), 10% sodium hydroxide solution (5 c.c.) was added gradually, with stirring. The mixture became dark red and the *keto*-compound separated as an oil which became solid on rubbing; it crystallised from water or benzene in dark red needles (0·6 g.), m. p. 174° (Found: C, 57·1; H, 5·3. $C_{14}H_{12}ON_2$ requires C, 75·0; H, 5·35%). The compound formed yellow salts with mineral acids, which were hydrolysed to the red salts of the keto-compound; it was less soluble in water and in benzene than 2-keto-*N*-methylphenazine. By substituting ethyl sulphate for methyl sulphate in Kehrmann's preparation of 2-keto-*N*-methylphenazine (*loc. cit.*) a compound was produced identical with that described above.

4-*Keto*-N-*ethylphenazine.*—Phenazine ethosulphate (1·0 g.) and sodium carbonate (0·16 g.) in water (1 l.) were kept in daylight with occasional shaking until colorimetric comparison showed no further production of the blue keto-compound (about 10 hours in sunlight; 4 days in diffuse light). Further sodium carbonate solution was added (40 c.c. of 10%), the whole extracted with chloroform, the extract dried (potassium carbonate), and the solvent removed; the residue crystallised from benzene in dark blue needles (0·55 g.), m. p. 187° (Found: C, 75·2; H, 5·3. $C_{14}H_{12}ON_2$ requires C, 75·0; H, 5·35%). The *compound* is less soluble in water and in benzene than is pyocyanine.

N-*Ethyldihydrophenazine.*—Phenazine ethosulphate (5 g.) in water (100 c.c.) and zinc dust (5 g.) were placed in a tap-funnel in an atmosphere of nitrogen, 20% sulphuric acid (20 c.c.) and ether (50 c.c.) added, and the whole, agitated by the gas stream, kept until the aqueous layer became colourless; it was then run off, and the ethereal solution of the *dihydro*-compound dried and evaporated under reduced pressure of nitrogen at room temperature. The residue (2·5 g.), recrystallised from benzene with minimal exposure to air, formed colourless prisms, m. p. (in nitrogen) 99° (Found: C, 80·2; H, 6·5. $C_{14}H_{14}N_2$ requires C, 80·0; H, 6·7%).

N-*Ethylphenazyl.*—*N*-Ethyldihydrophenazine (3·0 g.) in dry ether (120 c.c.) was shaken with dry lead peroxide (3 g.) and sodium sulphate (6 g.) for 10 hours. The rich red solution was filtered, concentrated, and cooled in ice-salt. An intensely red, crystalline precipitate formed, and was recrystallised from ether in the same manner, yielding the pure *phenazyl* (0·7 g.), m. p.

102° (Found : C, 80·7; H, 6·2; iodine equiv., 212, 214; *M*, in chloroform, 206, 219. $C_{14}H_{13}N_2$ requires C, 80·4; H, 6·2%; iodine equiv. and *M*, 209).

NN'-*Dimethyldihydrophenazine*.—To finely powdered phenazine methosulphate (1·0 g.) in ether (50 c.c.), stirred in a nitrogen atmosphere and cooled in ice, methylmagnesium iodide (from magnesium, 0·15 g.; methyl iodide, 0·4 c.c.) was added gradually. The mixture was refluxed for ½ hour and then washed with water; the yellow aqueous layer contained unchanged quaternary salt, recovered as the iodide (0·4 g.). The ethereal solution contained *N*-methyl-*NN'*-dihydrophenazine and *N*-methyldihydrophenazine. The latter (0·1 g.) was removed by washing with 5% sulphuric acid; the former (0·25 g.), obtained by removal of the ether, crystallised from benzene in colourless prisms, m. p. 152°, undepressed by the specimen previously prepared (Clemo and McIlwain, *loc. cit.*).

I wish to acknowledge my indebtedness to Professor R. Robinson for advice received in connection with this work, to Professor H. S. Raper for a preparation of tyrosinase, and to the Department of Scientific and Industrial Research for a research award.

Dyson Perrins Laboratory, Oxford University. [*Received, September 7th*, 1937.]

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360. *A New Reaction of 4 : 6-Ethylidene β-Methylglucoside Derivatives : 4 : 6-Dimethyl Glucose.*

By D. J. Bell and R. L. M. Synge.

By the use of a new reaction, crystalline 4 : 6-*dimethyl α-glucose* has been obtained from 4 : 6-*ethylidene β-methylglucoside* 2 : 3-*dinitrate as starting material, and its* constitution has been proved. The new sugar is shown to be the same as the crystalline dimethyl glucose of unknown constitution obtained by Haworth and Sedgwick (J., 1926, 2573).

This reaction consists in effecting, by acetic anhydride containing 0·1% of sulphuric acid, an opening of the 1 : 3-dioxan ring of the ethylidene β-methylglucoside derivative at C_6 of the glucose chain, giving rise to a derivative of 6-acetyl 4-α-acetoxyethyl β-methylglucoside.

The use of this reaction on 2 : 3-diacetyl 4 : 6-ethylidene β-methylglucoside leads to a rapid and economical preparation of 2 : 3 : 6-*triacetyl β-methylglucoside*.

The action of fuming nitric acid on some ethylidene β-methylglucoside derivatives has been studied, leading to the preparation of crystalline *β-methylglucoside 4 : 6-dinitrate*.

Twelve crystalline derivatives of β-methylglucoside are described for the first time.

This research originated in attempts to prepare a glucose derivative substituted in positions 1, 2, 3 and 6 by some radical, *e.g.*, the nitrate group, which does not display the migratory tendencies of carboxylic acyl groups and, unlike toluenesulphonyl radicals, can be removed without danger of Walden inversion. Our aim has not yet been realised, but we are reporting the discovery of a new reaction of the 4 : 6-ethylidene group in β-methylglucoside derivatives, analogous to that described for the 1 : 2-*iso*propylidene group in glucofuranose derivatives by Brigl and Zerrweck (*Ber.*, 1933, **66**, 936) and by Schlubach, Rauchenberger, and Schultze (*ibid.*, p. 1248). We have also succeeded in an efficient synthesis of crystalline 4 : 6-*dimethyl α-glucose*, which has been shown to be identical with the crystalline dimethyl glucose of unknown constitution obtained by Haworth and Sedgwick (J., 1926, 2573). We are indebted to Professor W. N. Haworth, F.R.S., for having the mixed melting point determinations carried out in his laboratory.

The reactions studied in the course of this work are summarised on page 1712, where B signifies β-methylglucoside.

Our investigations commenced with attempts to remove the ethylidene radical from 4 : 6-ethylidene β-methylglucoside 2 : 3-dinitrate, prepared by the method of J. W. H. Oldham (unpublished work from St. Andrews); the method consists in treating 4 : 6-ethylidene β-methylglucoside with a large excess of nitrogen pentoxide in chloroform. By the customary methods of mild acid hydrolysis for splitting acetal linkages, the initial material was largely recovered unchanged. More vigorous treatment with acid removed

the glucosidic methyl group, as did also treatment with acetic anhydride containing 1% of sulphuric acid at room temperature. The use of 0·1% sulphuric acid in this manner,

Section I.

4 : 6-*Ethylidene B* 2 : 3-*dinitrate* → *B* 2 : 3 : 4 : 6-*tetranitrate*; → ? 6-*Acetyl* 4-α-*acetoxyethyl B* 2 : 3-*dinitrate*

? 6-*Acetyl* 4-α-*acetoxyethyl B* 2 : 3-*dinitrate* → ? 6-*Acetyl B* 2 : 3 : 4-*trinitrate*; → *B* 2 : 3-*dinitrate*

B 2 : 3-*dinitrate* ⇄ 4 : 6-*Diacetyl B* 2 : 3-*dinitrate*

B 2 : 3-*dinitrate* → 4 : 6-*Dimethyl B* 2 : 3-*dinitrate* → 4 : 6-*Dimethyl B* → 4 : 6-*Dimethyl* α-*glucose*

4 : 6-*Dimethyl B* → 2 : 3-*Di*-p-*toluenesulphonyl* 4 : 6-*dimethyl B*

2 : 3-Di-*p*-toluenesulphonyl 4 : 6-benzylidene B → (2 : 3-Di-*p*-toluenesulphonyl B) → 2 : 3-*Di*-p-*toluenesulphonyl* 4 : 6-*dimethyl B*

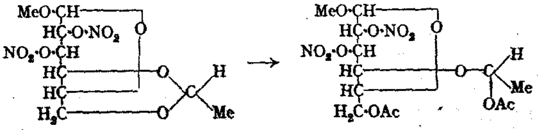
Section II.

2 : 3-Diacetyl 4 : 6-ethylidene B → 2 : 3-Diacetyl B 4 : 6-dinitrate → *B* 4 : 6-*dinitrate* → 2 : 3-Dimethyl B 4 : 6-dinitrate

2 : 3-Diacetyl 4 : 6-ethylidene B → (2 : 3 : 6-Triacetyl-4-α-acetoxyethyl B) → 2 : 3 : 6-*Triacetyl B* 4-*nitrate* ⇅ 2 : 3 : 6-Triacetyl B

Compounds in parentheses have not been characterised.

however, resulted in the formation of a new crystalline compound in about 60% yield; the rest of the initial material could be recovered unchanged. From the fact that the optical rotation of the mixture attained a constant value after 5 minutes at room temperature, we believe that an equilibrium results during this reaction. We suggest that the new compound is 6-*acetyl* 4-α-*acetoxyethyl* β-*methylglucoside* 2 : 3-*dinitrate*, formed by acetolytic opening of the 1 : 3-dioxan ring at C_6 of the glucose chain:



The proposed structure is supported by (1) the analytical figures, (2) the molecular weight, and the following reactions: (3) Treatment of the compound with sodium methoxide

at room temperature in equal volumes of chloroform and methyl alcohol yields crystalline *β-methylglucoside* 2 : 3-*dinitrate* (see below). (4) On treatment with dilute acid an amorphous product is obtained containing 9·2% OMe (calc. for monoacetyl β-methylglucoside dinitrate, 9·5%). During this treatment the optical rotation tends towards a constant value, and approximately one equivalent of acid per molecule is set free. The product proved very resistant to *p*-toluenesulphonylation by the usual method, with the result that we could not employ this method for proving its constitution. The yield of product, and the fact that it is extracted from water by chloroform, tend to confirm the view that the action of dilute acid is to remove the α-acetoxyethyl group, but further investigation is necessary before detailed information about the structure of the product can be given. (5) Treatment of the compound with fuming nitric acid in chloroform gave a good yield of a crystalline compound having the composition of a monoacetyl β-methylglucoside trinitrate. This substance proved completely resistant to deacetylation by the Zemplén technique. Dilute dimethylamine in alcohol similarly had no effect. More drastic treatment removed nitrate as well as acetate. Owing to this behaviour it was not possible to determine the structure by the usual methods. It was accordingly treated with sodium iodide in acetone under the conditions prescribed by Irvine and Oldham (J., 1925, **127**, 2729) and gave a completely halogen-free product; from this we conclude that in this compound the 6-position of the glucose residue is not occupied by nitrate, since in all known 6-nitrates of glucose derivatives the effect of this treatment is to yield the corresponding iodohydrin (Irvine and Oldham, *loc. cit.*; Oldham, *ibid.*, p. 2840; Oldham and Rutherford, *J. Amer. Chem. Soc.*, 1932, **54**, 366; Irvine and Rutherford *ibid.*, p. 1491). (6) By analogy with the corresponding series of reactions of 2 : 3-diacetyl 4 : 6-ethylidene β-methylglucoside (see below) leading to the formation of 2 : 3 : 6-triacetyl β-methylglucoside 4-nitrate. The action of fuming nitric acid is considered in each case to lead to a direct replacement by nitrate of the α-acetoxyethyl group. (7) A strong smell of acetaldehyde was noticed as a result of treating the compound with dilute acid, sodium methoxide, or fuming nitric acid.

The above reasons suggest that the α-acetoxyethyl group in this compound is situated at position 4 and not at position 6; direct proof has not succeeded, owing to the abnormal reactivities of the two derivatives mentioned above, and until this is achieved, the proposed formula must remain tentative.

β-Methylglucoside 2 : 3-dinitrate [see (3) above] was formed in almost quantitative yield, and on acetylation gave a well-defined *diacetyl* derivative from which the original material could easily be regenerated by treatment with sodium methoxide. Methylation of the 2 : 3-dinitrate with Purdie's reagents gave crystalline 4 : 6-*dimethyl β-methylglucoside* 2 : 3-*dinitrate*; this on reductive treatment with sodium sulphide yielded crystalline 4 : 6-*dimethyl β-methylglucoside*.

The constitution of the last substance follows from the method of preparation, but additional confirmatory evidence was obtained as below: (1) The substance yielded a crystalline di-*p*-toluenesulphonyl derivative identical with 2 : 3-*di*-p-*toluenesulphonyl* 4 : 6-*dimethyl β-methylglucoside* prepared as follows: 2 : 3-di-*p*-toluenesulphonyl 4 : 6-benzylidene β-methylglucoside was prepared by the method of Ohle and Spencker (*Ber.*, 1928, **61**, 2387). The crude material had m. p. 158°, that given by Ohle and Spencker. On recrystallisation, however, the melting point rose to 182—184°, $[\alpha]_D$ in chloroform being − 65·3°, as against the value − 54·7° given by the above authors. After elimination of the benzylidene group (which showed greater stability in the toluenesulphonyl derivative than in the corresponding benzoyl or acetyl compound) by acid hydrolysis, the product was methylated and yielded a crystalline substance which, since there is no evidence that the toluenesulphonyl group is capable of migration, has the constitution suggested above. (2) The ditoluenesulphonyl derivative, treated with sodium iodide and acetone at 100° according to Oldham and Rutherford, was quantitatively recovered, indicating that a toluenesulphonyl group did not occupy position 6 (*J. Amer. Chem. Soc.*, 1932, **54**, 366). (3) The dimethyl β-methylglucoside on acid hydrolysis gave a crystalline dimethyl glucose, m. p. 156—158°, $[\alpha]_D^{17°}$ (water) + 110·2° ($l = 2, c = 2·5$) (initial value, extrapolated from readings made in first 10 mins.) reaching + 63·6° in 24 hours, this value remaining unchanged during the next 12 hours; $[\alpha]_D^{22°}$ (pure dry methyl alcohol) ($l = 2, c = 1$) + 122° initially,

reaching a final value of + 85·0° in 36 hours (no change during the last 12 hours), which was not altered by the addition of a trace of ammonia. It did not depress the melting point of the dimethyl glucose of Haworth and Sedgwick (*loc. cit.*), for which the properties given were: m. p. 156—157°, $[\alpha]_D$ (in water) + 93·1° initially, falling to + 62·4°, $[\alpha]_D$ (in methyl alcohol) + 110·7°, falling to + 64·7° after catalysis.

On this evidence we suggest that, in spite of the differences in observed rotation, which may be due to differences of solvent, small traces of impurities, etc., our dimethyl glucose and that of Haworth and Sedgwick are the same compound. These authors demonstrated by methylating the compound that it had the structure of a glucopyranose, obtaining 2 : 3 : 4 : 6-tetramethyl glucose after hydrolysis of the resulting glucosides.

On treatment with methyl alcohol containing 1% of hydrogen chloride at room temperature, our compound had initially a specific rotation of + 85·2°, reaching + 64·2° after 6½ hours and + 61·3° after 22½ hours, at which value it remained for 3 days. This behaviour contrasts strongly with that of methylated glucoses in which position 4 is unsubstituted, with which condensation to give methylfuranosides can occur. Thus, for example, 2 : 3 : 6-trimethyl glucose, treated in this manner, has a negative rotation within 2 hours.

The above evidence suggests that in our dimethyl glucose and its β-methylglucoside, position 4 is substituted with methyl, while the experiment described in (2) above suggests that the same is true for position 6. We therefore formulate the dimethyl glucose as 4 : 6-dimethyl α-glucose, being the formula anticipated as a result of the method of preparation of the compound and its derivatives.

In order further to explore the action of acetic anhydride containing 0·1% of sulphuric acid on the ethylidene group, we subjected 2 : 3-diacetyl 4 : 6-ethylidene β-methylglucoside to this treatment. The amorphous product was not further examined, since on treatment with fuming nitric acid in chloroform it gave a good yield of crystalline 2 : 3 : 6-triacetyl β-methylglucoside 4-nitrate, identical with the product obtained from 2 : 3 : 6-triacetyl β-methylglucoside by the action of fuming nitric acid (J. W. H. Oldham, unpublished work). The constitution was confirmed by subjecting the new compound to reduction with zinc and iron in acetic acid solution, 2 : 3 : 6-triacetyl β-methylglucoside being obtained in good yield. The overall yield of the latter substance from 4 : 6-ethylidene β-methylglucoside is roughly 40%, and this preparation is therefore, in addition to being more rapid, considerably more economical than either of the previously described methods (Helferich, Bredereck, and Scheidmüller, *Annalen*, 1927, **458**, 111; Levene and Raymond, *J. Biol. Chem.*, 1932, **97**, 763). Our measurement of the rotation in chloroform (— 59·7°) for this compound incidentally confirms the Levene value (— 59·0°) as against the Helferich value (— 64·9°).

As a result of the foregoing experiments, we deduce that the action of acetic anhydride and sulphuric acid on the ethylidene derivative is in the main an acetolytic opening of the 1 : 3-dioxan ring at C_6 of the glucose chain, giving 2 : 3 : 6-triacetyl 4-α-acetoxyethyl β-methylglucoside.

An alternative method for removing the ethylidene group is afforded by the direct action of fuming nitric acid, analogous to a reaction of the benzylidene group employed by Oldham and Rutherford (*J. Amer. Chem. Soc.*, 1932, **54**, 366), but more conveniently carried out, owing to the absence of aromatic by-products. In this way from the ethylidene dinitrate, we obtained crystalline β-methylglucoside 2 : 3 : 4 : 6-tetranitrate, a compound not previously described, but mentioned in an analytical paper by Brough and Dewar (*J. Soc. Chem. Ind.*, 1936, **55**, 207T).

Acting on 2 : 3-diacetyl 4 : 6-ethylidene β-methylglucoside, fuming nitric acid gave a good yield of crystalline 2 : 3-diacetyl β-methylglucoside 4 : 6-dinitrate, the characterisation of which is here described for the first time, although the compound is mentioned in passing by Oldham and Rutherford (*loc. cit.*). Treatment of this with sodium methoxide in chloroform caused *β-methylglucoside 4 : 6-dinitrate* to crystallise from the reaction mixture, in which it was only slightly soluble; methylation of this substance gave crystalline 2 : 3-dimethyl β-methylglucoside 4 : 6-dinitrate, identical with that prepared by Oldham and Rutherford (*loc. cit.*).

Experimental.

Unless otherwise stated, all evaporations were carried out under reduced pressure and below 50°. Substances were recrystallised until a constant m. p. was attained.

4 : 6-*Ethylidene* β-*Methylglucoside* 2 : 3-*Dinitrate* (I).—(Instructions for this preparation were afforded us by Dr. Oldham.) A suspension of 2 g. of 4 : 6-ethylidene β-methylglucoside (Helferich and Appel, *Ber.*, 1931, **64**, 1841) in 54 ml. of dry chloroform was cooled with ice, and 18 ml. of a cold solution of 20 g. of nitrogen pentoxide in 100 ml. of dry chloroform added. The mixture was stirred until all had dissolved, kept in ice for 5 minutes, and poured into a large volume of ice-water. The chloroform layer was washed with potassium bicarbonate solution, dried over sodium sulphate, and evaporated to dryness. The colourless syrup obtained crystallised from light petroleum (b. p. 60—80°) or alcohol in stout needles, m. p. 88—89°, $[\alpha]_D^{19°}$ (chloroform) − 21·0° (l = 2, c = 5) (Found : N, 9·3; OMe, 10·7. Calc. for $C_9H_{14}O_{10}N_2$: N, 9·05; OMe, 10·0%). The yield was 95% of the theoretical; if more than 2 g. of the initial material was used in one batch, the yield was considerably less, *e.g.*, 60% from a batch of 5 g.

6-*Acetyl* 4-α-*Acetoxyethyl* β-*Methylglucoside* 2 : 3-*Dinitrate* (II).—The optical rotation of a 5% solution of (I) in acetic anhydride was negative. If, however, the solution was made up with acetic anhydride containing 0·1% of sulphuric acid, a positive rotation was observed. This had reached a constant value before observation could begin, and remained constant for 24 hours. Investigation of this phenomenon led to the following preparation of (II). A solution of 10 g. of (I) in 200 ml. of acetic anhydride containing 0·2 ml. of sulphuric acid was kept at room temperature for 5 minutes, 5 vols. of ice-water containing a little sodium acetate added, and the mixture stirred until a stiff crystalline mass was obtained. The mixture was extracted with benzene, the extract washed with potassium bicarbonate solution, dried (sodium sulphate), and evaporated to dryness, and the crystalline residue recrystallised from alcohol, giving fine needles, m. p. 113—115°, $[\alpha]_D^{17°}$ (chloroform) + 22·7° (l = 2, c = 3) (Found : C, 38·2; H, 4·65; N, 6·45; OMe, 8·0; *M*, cryoscopic in acetic acid, 410. $C_{13}H_{20}O_{13}N_2$ requires C, 38·0; H, 4·8; N, 6·8; OMe, 7·5; *M*, 412.

The *substance* (II) was formed in about 60% yield, and more could be obtained by evaporating the mother-liquors (which did not yield another crop of crystals) and repeating the treatment with acetic anhydride and sulphuric acid on the syrup so obtained. This indicates that the reaction does not proceed to completion. This view is confirmed by treating the crude product of the reaction with sodium methoxide, under the conditions detailed below, and subjecting the new product to benzene–water extraction; unchanged (I) can then be obtained crystalline from the benzene layer.

Acid hydrolysis of (II). 1 G. of (II) was dissolved in 27 ml. of acetone and 3 ml. of N-hydrochloric acid. The rotation was observed in a 2 dm. tube : α + 1·57° (initial value), + 0·64° after 40 minutes' refluxing on the water-bath, + 0·02° after 70 mins., − 0·56 after 130 mins., and − 0·63° after 170 mins. During this treatment a strong smell of acetaldehyde was noticed. The mixture was then titrated with N-sodium hydroxide until neutral to phenolphthalein : 5·8 ml. were required, *i.e.*, during hydrolysis 2·8 milliequivs. of acid were liberated, *i.e.*, 1·15 equivs. of acid per molecule. A drop of acetic acid was then added, then excess of potassium bicarbonate solution, and the mixture extracted twice with chloroform; 0·68 g. of a colourless syrup was obtained on evaporation of the chloroform. It could not be crystallised, and on treatment under the usual conditions with *p*-toluenesulphonyl chloride in pyridine gave only 0·3 g. of uncrystallisable product.

6-*Acetyl* β-*Methylglucoside* 2 : 3 : 4-*Trinitrate* (III).—4 G. of (II) were dissolved in 20 ml. of chloroform and cooled to 0°, 20 ml. of fuming nitric acid + 20 ml. of chloroform, also cooled to 0°, were added, and the mixture was kept in ice for 15 minutes and then poured into a large excess of ice-water. The chloroform layer was separated, washed with potassium bicarbonate solution, dried (sodium sulphate), and evaporated; a strong smell of acetaldehyde was observed. The colourless syrup obtained yielded stout, compact crystals (2·2 g.) on treatment with alcohol. A further yield could be obtained by subjecting the material in the mother-liquor to repeated nitric acid treatment. The material, recrystallised from alcohol, had m. p. 104—105°, $[\alpha]_D^{17·8°}$ (chloroform) − 27·0° (l = 2, c = 2·5) (Found : C, 29·4; H, 3·5; N, 10·7; OMe, 8·5. $C_9H_{13}O_{13}N_3$ requires C, 29·15; H, 3·5; N, 11·3; OMe, 8·4%). The *compound* (III) could be recovered for the most part unchanged after treatment with 0·2 mol. of sodium methoxide in equal vols. of chloroform and methyl alcohol for an hour at room temperature.

1 G. of (III) was heated for 6 hours at 100° in a sealed tube with 1 g. of sodium iodide and 10 ml. of acetone. The product was largely diluted with water containing sodium thiosulphate, and extracted twice with chloroform. On evaporation the chloroform yielded 0·3 g. of a yellow

syrup which could not be crystallised. This gave a negative response to the Lassaigne halogen test after complete removal of the chloroform.

β-Methylglucoside 2 : 3-Dinitrate (IV).—10 G. of (II) were dissolved in 100 ml. of chloroform, and 100 ml. of methyl alcohol, in which 0·12 g. of sodium had immediately beforehand been dissolved, were added. The mixture, which gave off a smell of acetaldehyde, was kept at room temperature for ½ hour; 0·4 ml. of acetic acid was then added, and the solution evaporated to dryness. The resulting syrup was dissolved in water and washed with a little benzene, which on separation yielded only 30 mg. of non-volatile matter. The aqueous solution was evaporated in the presence of a little barium carbonate, the product dissolved in ether, and the solution filtered through animal charcoal. On evaporation it yielded a colourless, almost solid glass, which, after standing over phosphoric oxide for 4 days, crystallised in needles; these could be recrystallised from ether–light petroleum (b. p. 50—60°). A quantitative yield was obtained. For further stages of the work, the glass could be used directly, without recrystallisation, as it was evidently very pure. The compound had m. p. 96—98°, $[\alpha]_D^{20°}$ (chloroform containing 5% of acetone, to assist solution) − 20·5° (l = 2, c = 2·5) (Found: N, 9·8; OMe, 11·2. $C_7H_{12}O_{10}N_2$ requires N, 9·9; OMe, 10·9%).

4 : 6-*Diacetyl β-Methylglucoside 2 : 3-Dinitrate* (V).—Acetylation of (IV) by either acetic anhydride and sodium acetate or acetic anhydride and pyridine gave a good yield of this *compound*, which, recrystallised from alcohol, formed stout needles, m. p. 138—140°, $[\alpha]_D^{18°}$ (chloroform) − 5·2° (l = 2, c = 4) (Found: C, 36·9; H, 4·9; N, 8·0; OMe, 7·8. $C_{11}H_{16}O_{12}N_2$ requires C, 35·85; H, 4·35; N, 7·6; OMe, 8·4%).

4 : 6-*Dimethyl β-Methylglucoside 2 : 3-Dinitrate* (VI).—1·6 G. of (IV) was methylated for 4 hours at 45° in excess of methyl iodide in the presence of 4·8 g. of silver oxide. The resulting mixture was taken up in ether, the solution filtered through charcoal, and the filtrate evaporated; the colourless syrup (1·76 g.) obtained shortly crystallised in a high vacuum and on recrystallisation from light petroleum the *product* formed needles, m. p. 54—57°, $[\alpha]_D^{18°}$ (chloroform) − 13·4° (l = 2, c = 3) (Found: N, 8·6; OMe, 29·8. $C_9H_{16}O_{10}N_2$ requires N, 9·0; OMe, 29·8%).

4 : 6-*Dimethyl β-Methylglucoside* (VII).—2 G. of (VI) were dissolved in 10 ml. of alcohol, and 10 ml. of 30% sodium hydroxide solution saturated with hydrogen sulphide were added. After refluxing for ½ hour on the water-bath, the alcohol was removed, potassium carbonate dissolved in the solution until chloroform would just sink, and the solution then extracted nine times with equal volumes of chloroform (cf. Bell, *Biochem. J.*, 1932, 26, 590). The combined chloroform extracts were dried over sodium sulphate, and evaporated to give a pale yellow syrup. This distilled almost quantitatively at 130—160°/0·4 mm. The distillate crystallised in fine needles (yield, about 70%) and after recrystallisation from ether had m. p. 50—52° and had $[\alpha]_D^{18°}$ (chloroform) − 28·8° (l = 2, c = 3) (Found: OMe, 41·5. $C_9H_{18}O_6$ requires OMe, 41·8%).

2 : 3-*Di*-p-*toluenesulphonyl* 4 : 6-*Dimethyl β-Methylglucoside* (VIII).—(A) A mixture of 0·32 g. of (VII), dissolved in the minimum quantity of pyridine with 0·8 g. of *p*-toluenesulphonyl chloride, was kept at 37° for 48 hours and the product was worked up in the usual manner with benzene and crystallised from alcohol. On recrystallisation, the material had m. p. 146—149°, $[\alpha]_D^{20°}$ (chloroform) − 14·8° (l = 2, c = 3) (Found: S, 11·8; OMe, 17·3. $C_{23}H_{30}O_{10}S_2$ requires S, 12·1; OMe, 17·55%).

(B) 12 G. of 2 : 3-di-*p*-toluenesulphonyl 4 : 6-benzylidene β-methylglucoside (X), prepared by the method of Ohle and Spencker (*loc. cit.*) (Found: S, 10·8; OMe, 5·4. Calc. for $C_{28}H_{30}O_{10}S_2$: S, 10·85; OMe, 5·3%), were dissolved in 190 ml. of acetone and 10 ml. of 2N-sulphuric acid. The rotation was measured after 2 hours' refluxing (− 7·6°), 2·75 hours (− 3·4°), 3·75 hours (− 3·0°). The mixture was then neutralised with barium carbonate, and evaporated. The benzaldehyde remaining was removed by addition of water and re-evaporation. On addition of alcohol, crystals of unchanged (X) were obtained, so the product was taken up in 200 ml. of acetone and 100 ml. of 0·3N-hydrochloric acid and refluxed again for 7 hours. The benzaldehyde was removed as previously, and the product taken up in chloroform and alcohol and filtered through charcoal. The filtrate on evaporation yielded 10 g. of 2 : 3-di-*p*-toluenesulphonyl β-methylglucoside (IX) as a syrup which could not be crystallised. This was methylated with 15 ml. of methyl iodide and 15 g. of silver oxide; the product gave crystals from alcohol (VIII), m. p. 146—149° (undepressed by specimen A), $[\alpha]_D^{20°}$ (chloroform) − 14·6° (l = 2, c = 5·5) (Found: S, 12·2; OMe, 17·4%).

4 : 6-*Dimethyl α-Glucose* (XI).—2 G. of (VII) were boiled under reflux with 40 ml. of N-hydrochloric acid and the rotation was observed in a 2 dm. tube: 90 mins., + 3·59°; 120 mins., 4·37°; 190 mins., 5·25°; 335 mins., 5·90°. The solution was then cooled, neutralised with excess

of pure lead carbonate, kept in ice for a few minutes, and filtered; the precipitate was washed with alcohol, and the combined filtrate and washings were evaporated under reduced pressure at 100°. The product was extracted four times with boiling ethyl acetate, and the extract filtered hot. On cooling, crystals were immediately deposited. Recrystallised from ethyl acetate, these formed fine needles, m. p. 156—158° (Found: C, 45·5; H, 7·8; OMe, 29·95. $C_8H_{16}O_6$ requires C, 46·15; H, 7·7; OMe, 29·8%). The *compound* did not depress the m. p. of the crystalline dimethyl glucose of Haworth and Sedgwick (*loc. cit.*) (experiment carried out by Prof. Haworth, at Birmingham).

71 Mg. of the compound were dissolved in 5 ml. of methyl alcohol (bench reagent) containing 1% of dry hydrogen chloride. The rotation was measured in a 1 dm. tube at 23°:

Time (hrs.)	0	$\frac{1}{4}$	$1\frac{1}{4}$	$4\frac{1}{4}$	$6\frac{1}{4}$	$22\frac{1}{4}$
α	+ 1·21°	+ 1·16°	+ 1·07°	+ 0·94°	+ 0·91°	+ 0·87°
$[\alpha]_D$	+85·2°	+81·7°	+75·4°	+66·2°	+64·2°	+61·3°

2 : 3 : 6-*Triacetyl* 4-α-*Acetoxyethyl* β-*Methylglucoside* (XIII).—6·5 G. of 2 : 3-diacetyl 4 : 6-ethylidene β-methylglucoside (XII) (Helferich and Appel, *Ber.*, 1931, **64**, 1841) were dissolved in acetic anhydride (130 ml.) containing 0·1% of sulphuric acid. The rotation observed in a 1 dm. tube was − 3·19° initially (without sulphuric acid), + 0·03° after 5 mins., and + 0·07° after 10 mins. Ice-water (5 vols.) with a little sodium acetate was then added, and the mixture on stirring soon became homogeneous. The solution was neutralised with excess of calcium carbonate and filtered, and the precipitate washed with chloroform, which was subsequently used for extracting the filtrate. The chloroform extracts on drying and evaporation yielded 6·4 g. of a colourless syrup, which did not crystallise (XIII).

2 : 3 : 6-*Triacetyl* β-*Methylglucoside* 4-*Nitrate* (XIV).—(A) 1 G. of (XIII) was treated with fuming nitric acid in chloroform and worked up exactly as described for the preparation of (III); 0·8 g. of a colourless syrup was obtained, which did not crystallise immediately on addition of alcohol, but gave crystals (0·74 g.) on addition of water to the methyl-alcoholic solution to turbidity, followed by a trace of ether. Recrystallisation from methyl alcohol gave a pure *product*, m. p. 112—114°, $[\alpha]_D^{17.5°}$ (chloroform) − 27·0° (l = 2, c = 2·5) (Found: C, 42·65; H, 5·0; N, 3·5; OMe, 8·1. $C_{15}H_{19}O_{11}N$ requires C, 42·75; H, 5·2; N, 3·8; OMe, 8·5%).

(B) (Oldham's method). 140 Mg. of 2 : 3 : 6-triacetyl β-methylglucoside (XV), prepared by the method of Levene and Raymond (*J. Biol. Chem.*, 1932, **97**, 763), were treated with fuming nitric acid in chloroform exactly as described above, and worked up to give 183 mg. of a colourless syrup, which crystallised from methyl alcohol; m. p. 112—114° (undepressed by A), $[\alpha]_D^{24°}$ (chloroform) − 26·9° (l = 2, c = 1·7).

2·4 G. of (XIV) were dissolved in 15 ml. of glacial acetic acid and reduced with iron filings and zinc dust until the solution gave no colour with diphenylamine in sulphuric acid. It was then diluted with water, neutralised with excess of barium carbonate, and filtered. The precipitate was washed with chloroform, which was then used for extracting the filtrate. The chloroform extract on evaporation yielded 2·2 g. of a colourless syrup, which crystallised immediately on addition of ether. Recrystallisation was effected by concentrating and cooling an ethereal solution of the material; the product had m. p. 112—115° and did not depress the m. p. of authentic (XV). $[\alpha]_D^{23°}$ (chloroform) − 59·7° (l = 2, c = 3·3). Levene and Raymond (*loc. cit.*) give m. p. 113·5—114·5° and $[\alpha]_D$ − 59·0°.

β-*Methylglucoside* 2 : 3 : 4 : 6-*Tetranitrate* (XVI) (cf. Brough and Dewar, *loc. cit.*).—2 G. of (I) were treated with fuming nitric acid in chloroform and worked up exactly as described above for the preparation of (III); 2·7 g. of a syrup were obtained, which gave stout needles from alcohol, m. p. 116—118°, $[\alpha]_D^{17°}$ (chloroform) + 9·35° (l = 2, c = 4) (Found: N, 14·15; OMe, 8·15. Calc. for $C_7H_{10}O_{14}N_4$: N, 15·0; OMe, 8·3%).

2 : 3-*Diacetyl* β-*Methylglucoside* 4 : 6-*Dinitrate* (XVII) (cf. Oldham and Rutherford, *loc. cit.*).—2 G. of (XII) were dissolved in chloroform and treated with fuming nitric acid exactly as described for the preparation of (III). 2·27 G. of a colourless syrup were obtained, which gave fine needles from methyl alcohol, m. p. 118—120°, $[\alpha]_D^{18°}$ (chloroform) − 7·3° (l = 2, c = 5) (Found: N, 7·15; OMe, 8·4. $C_{11}H_{16}O_{12}N_2$ requires N, 7·6; OMe, 8·4%).

β-*Methylglucoside* 4 : 6-*Dinitrate* (XVIII).—7 G. of (XVII) were dissolved in 70 ml. of chloroform, and to the solution were added 5 ml. of methyl alcohol in which 0·1 g. of sodium had been dissolved immediately beforehand. The mixture was kept at room temperature and after 100 minutes a mat of fine needle-like crystals had separated (yield, 4·3 g.; 80% of the theoretical). The crystals were very slightly soluble in boiling chloroform and extremely soluble in cold alcohol. Recrystallisation was best effected from water; m. p. 147—149°, $[\alpha]_D^{17°}$ (methyl alcohol,

pure B.D.H.) $-$ 5·3° (l = 2, c = 2) (Found: N, 9·0; OMe, 10·85. $C_7H_{12}O_{10}N_2$ requires N, 9·9; OMe, 10·9%).

This substance, on a single treatment with methyl iodide and silver oxide, yielded a quantitative amount of product crystallising from alcohol; m. p. 98—99°, not lowered by authentic *2 : 3-dimethyl β-methylglucoside 4 : 6-dinitrate of the same m. p.*; $[\alpha]_D^{20°}$ (chloroform) $-$ 19·95° (l = 2, c = 1·3). Oldham and Rutherford (*loc. cit.*) give m. p. 98—99°, $[\alpha]_D$ (chloroform) $-$ 20·8° (c = 3).

The authors wish to record their gratitude to Dr. J. W. H. Oldham for much helpful advice.

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361. *The Direct Conversion of Iodic Acid and Aromatic Hydrocarbons into Iodonium Compounds.*

By IRVINE MASSON and EDWARD RACE.

Iodic acid in suitable concentrations of sulphuric acid attacks aromatic compounds C_6H_5X (where X = H, CH_3, Cl, Br, I) to give the iodonium radical $(C_6H_4X)_2I^{\cdot}$. The *reaction is of a new type, and its mechanism is studied. The yields are high and the* method is in these cases the simplest for preparing iodonium compounds; it incidentally furnishes a quick and delicate test for aromatic hydrocarbons in paraffins. The case of chlorobenzene has chiefly been investigated. Accompanying the iodonium radical, there is produced an iodine-free reducing agent, apparently an open-chain unsaturated acid, the product of oxidation of part of the organic reagent. A by-product, the formation of which may be largely suppressed under proper working conditions, is the iodo-derivative of the aromatic reagent.

The mechanism of the process is dealt with experimentally; various hypotheses are thus excluded, and evidence is given that it consists of a primary deoxidation of the *iodic acid to the iodous stage by a fraction of the aromatic reagent (which is thereby* converted into the open-chain unsaturated substance), followed by the direct interaction of the "iodous acid" and the aromatic reagent to give the diaryliodonium radical. *The latter interaction is also new; it is shown experimentally to proceed*, quantitatively, with an inorganic iodous compound, independently prepared; and by considering the properties of iodous iodine it is concluded that this is an ionic reaction: $I^{+++} + 2RH \longrightarrow 2H^+ + R_2I^+$ or alternatively $IO^+ + 2RH \longrightarrow H_2O + R_2I^+$. The need for a sulphuric acid medium is at the same time explained.

Facts are mentioned which are thought to relate to the condition of the ions in iodonium salts $R_2I{\cdot}X$, and to the mechanism of their known thermal decomposition into RI + RX.

Full analytical data are stated, with notes of precautions.

IN a paper on the chemistry of iodoxy-compounds (Masson, Race, and Pounder, J., 1935, 1669) it was mentioned that that work had arisen from a reaction, discovered by one of us, in which benzene derivatives and iodic acid in sulphuric acid formed diaryliodonium salts in high yield. This reaction, for which we have not found any precedent or analogy, is the subject of the present paper.

For the better control of the reaction, and for the sake of a closer diagnosis of its nature, the bulk of this work has been done with chlorobenzene in preference to benzene itself or other derivatives, which have, however, been partly studied; and an explanation of the reaction has been reached. In a number of cases, this reaction affords much the simplest and most economical way to make iodonium compounds; it also affords a very quick, easy, and decisive test for the presence of traces (or more) of aromatic hydrocarbons in other hydrocarbon oils (see p. 1719).

If benzene, toluene, chloro-, bromo-, or iodo-benzene is shaken, at or below room temperature, with a suspension of iodine pentoxide in concentrated sulphuric acid, a rapid reaction occurs which in a few minutes forms a dark solution. When this is diluted with ice or cold water, an oily flocculus is precipitated; this, which is essentially the iodo-

substitution product of part of the aromatic reagent, is a by-product, mainly avoidable under the controlled conditions to be described. The acid liquor separated from it gives, when treated with sulphur dioxide or sodium iodide or both, a bulky whitish or yellow precipitate which is the diaryliodonium iodide. Alternatively, the acid liquor may be diluted so as to make the sulphuric acid in it 8N., whereupon an oil separates, which crystallises later and is the iodonium hydrogen sulphate, a substance with interesting physico-chemical characteristics. In all these cases the linkage between the aromatic nucleus and the iodine of the iodonium radical is exclusively in the *para*-position to the methyl or halogen substituent.

With anisole and other highly reactive or oxidisable benzene derivatives, it is difficult to obtain more than traces of an iodonium product; even under carefully controlled conditions, drastic decompositions predominate. On the other hand, when the substituent is *meta*-directing, as with nitrobenzene, scarcely any reaction is observed, though a little iodonium derivative is slowly formed.

The practical success of the reaction depends, as in nitrations, upon choosing the proper degree of hydration of the sulphuric acid, upon maintaining this despite the water set free by the action itself, and upon keeping the temperature from rising. For instance, for benzene, the concentration of the acid should not be weaker than $H_2SO_4 : 2H_2O$, and should not exceed $H_2SO_4 : 1{\cdot}2H_2O$; and the temperature should be below 10°, preferably 0°. For chlorobenzene, a less vigorous reagent, the acid should be $2H_2SO_4 : 1H_2O$, and the temperature should be between 15° and 25°. (In using the reaction as a test for aromatic impurity in paraffins, ordinary concentrated sulphuric acid, $3{\cdot}5H_2SO_4 : 1H_2O$, is safe; powdered sodium iodate can be used in place of iodine pentoxide; and the volume of oil so tested need not exceed 2 or 3 c.c. The product is poured into water, separated, and filtered, and the solution treated with sulphur dioxide; the flocculent iodonium iodide precipitates at once or, with only minute traces, after some time.)

Using chlorobenzene (2 mols. to 0·5 mol. of iodine pentoxide), and working strictly quantitatively under a variety of conditions of temperature, of concentration of sulphuric acid, and of the mode of mixing the reagents, we can account for as much as 98% of the initial iodine and 85% of the initial chlorophenyl groups, in the yield of bis-(*p*-chlorophenyl)iodonium salt, with some of its decomposition product *p*-chloroiodobenzene, and a trace of free iodine. No oxidising agent is left.

It will be seen that, besides the missing 15% of chlorophenyl groups, one-third of the initial oxygen atoms are also unaccounted for:

$$HIO_3 + 2RH + H_2SO_4 \longrightarrow R_2I{\cdot}HSO_4 + 2H_2O + (O).$$

This "disappearance" of one oxygen atom per iodonium radical formed has a parallel in the interaction of iodosobenzene and concentrated sulphuric acid:

$$2C_6H_5{\cdot}IO + H_2SO_4 \longrightarrow (C_6H_4I)(C_6H_5)I{\cdot}HSO_4 + H_2O + (O),$$

in which Meyer and Hartmann first discovered the existence of iodonium compounds. They showed (*Ber.*, 1894, **27**, 426) that the oxygen did not survive in any oxidising agent, and that it was not evolved as such; but they did not further pursue the point, remarking "offenbar wird der Sauerstoff zur Oxydation eines kleines Theiles der Substanz verbraucht." In our reaction, although we have not yet finally identified the dissolved substance which accounts for the missing oxygen, we have been able to disentangle its reactions from the complications which occur when it is in the presence of iodonium salts; and the evidence makes it most probable that the missing oxygen atom has broken the aromatic ring in the 15% of the organic reagent, to form (in the case of chlorobenzene) a chlorinated unsaturated aliphatic acid. The following facts from this section of the work bear upon the main reaction.

The main reaction liquor from experiments with chlorobenzene was deprived of most of its iodonium product as the crystalline hydrogen sulphate, the remainder was precipitated from the mother-liquor with sodium iodide, and the excess of iodide removed with excess of silver sulphate. The resulting solution contained a non-phenolic substance which reduces dilute permanganate strongly, absorbs bromine, is neither steam-volatile nor

extractable with benzene from acid or from alkaline solution, is destroyed (as a reducing agent) by alkali, but is precipitated with sulphate by barium carbonate. Oxidised in acid solution by permanganate in presence of silver sulphate, it yields hydrochloric acid (as silver chloride) and carbon dioxide; the oxygen content of the latter is 1·57 times that in the permanganate used to produce it (calc., *e.g.*, for chlorofumaric acid, 1·60). It is a remarkable fact, which we have not explained, that if the permanganate oxidation is done without previous removal of the iodonium product from solution, the latter is at once wholly decomposed at the same time as the reducing agent, forming *p*-chloroiodobenzene, and so also is additional iodonium salt if it is deliberately put into the liquor in limited quantity; yet the pure iodonium salt in the absence of the reducing agent is not at all affected by permanganate under conditions otherwise identical.

In the main reaction between iodic acid and chlorobenzene, the production of some carbon dioxide was observed; experiments were made in which this was collected quantitatively and weighed. It proved to represent no more than a few units % of the initial material, unless high reaction temperatures were allowed. It appears to be formed in a side reaction between some of the primary reducing agent just described and a small part of the iodic acid, which therefore acts in this secondary reaction much in the same way as did the permanganate in the tests above mentioned. The evidence also makes it probable that when low yields of iodonium salt occur, through the sulphuric acid being too concentrated or the temperature too high, the increase in aromatic iodo-compound at the expense of iodonium is largely due to the same peculiar breakdown of iodonium in the presence of the reducing agent and an oxidiser, as was noted in the premanganate oxidations.

The equation on p. 1719, together with the information given about the destination of the oxygen atom and the causes of iodonium loss, state adequately the balance sheet of substances, but they do not give a dynamically satisfying explanation of the sequence of action. Two hypotheses for this present themselves. One is that iodic acid and hydrocarbon first interact to form a complex, which then, or in analysis, undergoes fission into the diaryliodonium radical and organic degradation products. Such an initial interaction might, for instance, produce the sulphate of the diaryliodyl radical whose existence was disclosed in our earlier paper: $2RH + HIO_3 + H_2SO_4 \longrightarrow 2H_2O + R_2IO{\cdot}HSO_4$; or $3RH + HIO_3 + H_2SO_4 \longrightarrow 2H_2O + R_3IO,H_2SO_4$, a possible analogue of the tertiary phosphine or stibine oxides; or even $4RH + HIO_3 + H_2SO_4 \longrightarrow 3H_2O + R_4I{\cdot}HSO_4$, a possible quaternary iodonium salt.

We did, in fact, find suggestions of the formation and survival of some such precursor of iodonium; for example, the quantity of iodonium salt analytically got from the diluted reaction liquor was considerably greater than would be allowed by the solubility of the pure iodonium salt in acid of the same concentration, as found in separate measurements. But it is clear that the complex, if one were present, could not be a diaryliodyl compound, for the characteristic oxidising reactions of this were wholly lacking; and careful experiments have shown us that the analytical precipitation of actual diaryliodonium, from the solutions which would contain a supposed tertiary oxide or quaternary radical, did not release any other discoverable substance, such as would represent the organic remainder of the molecule of the hypothetical complex. Further, iodic acid did not react with more than 2 mols. of the aromatic reagent. Hence, plausible hypotheses of this kind are, on the experimental evidence, scarcely tenable, notwithstanding the initial indications in their favour.

The other hypothesis is that iodic acid produces iodonium only in virtue of its being first wholly reduced to "iodous acid," HIO_2 or I_2O_3, by its oxidising a part (*e.g.*, 15%) of the initial aromatic reagent so as to open the ring and form the unsaturated iodine-free acids already mentioned. The resulting iodous acid, as its iodine is already in the requisite condition of tervalency, might then be supposed to react: $2RH + OIOH \longrightarrow R_2I{\cdot}OH + H_2O$. This hypothesis has been fully borne out by the experiments in which we put it to the test; for, on preparing iodine sesquioxide (as a sulphate) we found that, in the appropriate sulphuric media, it at once attacks chlorobenzene or benzene very smoothly and cleanly and without noticeable heat, giving simply the pure iodonium radical in

quantitative yield. Further experiments on this and allied matters are in progress (cf. Masson, *Nature*, 1937, **139**, 150).

The known properties of iodine sesquioxide, however, enable us to understand its attack upon aromatic reagents (above) and consequently the course and the conditions of the reaction of iodic acid under discussion; for the inorganic preparative work of Fichter and Kappeler (*Z. anorg. Chem.*, 1915, **91**, 134), following Chrétien's original isolation of $I_2O_3,SO_3,0{\cdot}5H_2O$ (*Ann. Chim. Phys.*, 1898, **15**, 358), has clearly shown that I_2O_3 is a basic oxide towards powerful and concentrated acids. Accordingly, in our main reaction, all the iodic acid is gradually reduced by a fraction of the organic reagent (which thereby is degraded), but the reduction goes no further than to the iodous state, because the sulphuric acid stabilises this as an iodous sulphate; and the immediately ensuing reaction between this solute and the aromatic reagent, forming the iodonium salt which is the most obvious product of the reaction as a whole, is to be considered as a cationic attack. For instance, if the iodous cation is simply I^{+++}, corresponding to $I(HSO_4)_3$, the reaction is $I^{+++} + 2RH \longrightarrow 2H^+ + (R_2I)^+$, and if it is the univalent iodyl radical, as Chrétien's salt would suggest, the reaction is $IO^+ + 2HR \longrightarrow H_2O + (R_2I)^+$. The former alternative would entail a change in the electronic number of the iodous atom from 50 to 54; the latter need not call for any change from 54. These matters will be dealt with in the light of other experimental evidence, to be produced in later papers.

Notes on the Iodonium Salts.—Crystalline bis-(*p*-chlorophenyl)iodonium hydrogen sulphate undergoes, on treatment with water, a strikingly evident conversion into the crystalline anhydrous normal sulphate; as seen under the microscope, the process seems to go by way of a metastable oily form (also observed during the initial preparation of the hydrogen sulphate). The change is reversed in sulphuric acid, and the concentration of acid in which both solid phases are in equilibrium is near 6N.: $2\ R_2I{\cdot}HSO_4 \rightleftharpoons (R_2I)_2SO_4 + H_2SO_4$.

Organic solvents such as alcohols and acetone dissolve appreciable amounts of iodonium salts, particularly those in which the phenyl groups of the cation are already substituted; while water is commonly weaker as a solvent. Chloroform, whether freed from alcohol or not, has a notably specific effect upon the hydrogen sulphates (and possibly some other salts) which carbon tetrachloride has not; the salt partly dissolves as such, and to some extent undergoes fission, producing the aromatic iodo-compound. This is reminiscent of the specific effect of chloroform on the most heavily substituted quaternary ammonium halides, which are not only highly soluble in it (Peddle and Turner, J., 1913, **103**, 1202) but also, if they are optically active, are racemised by it, apparently by fission and re-union (Wedekind, Paschke, and Mayer, *Ber.*, 1911, **44**, 1406).

That a salt of an alkali-forming cation with a strong oxy-acid should have an oily form, besides solubilities such as are here indicated, points to marked polarisability of the anion by the cation. This interpretation is in no way inconsistent with the study of diphenyliodonium iodide by Juliusburger, Topley, and Weiss (J., 1935, 1295), wherein by using radioactive iodine they showed that the covalent iodine and the anionic iodine do not exchange places during aqueous reactions, or even during incipient thermal decomposition; nor does it conflict with the evidence from *X*-rays, by which Medlin showed that the distance between the two iodine atoms in the crystals of the same compound is compatible with an ionic structure, not with a covalent link (*J. Amer. Chem. Soc.*, 1935, **57**, 1026). Fletcher and Hinshelwood (J., 1935, 596) have shown the thermal decomposition of the iodide to be unimolecular, and have also measured the activation energies of the process in the solid state and in solution in iodobenzene. It seems clear that any strong interionic polarisation, the effects of which are to induce, as has been mentioned, properties tending towards those of covalent compounds, must play an important part in initiating the wholly irreversible fission which all iodonium salts undergo when they are heated, $R_2I{\cdot}X \longrightarrow RI + RX$, wherein the hitherto anionic X becomes covalently attached to one of the radicals R.

Experimental.

For lack of a more accurate word, and for the sake of brevity, we use the term " iodylation " for the operation in which iodic acid acts on an aromatic compound.

Conduct of an Iodylation.—The following characteristic example with chlorobenzene gives the practical directions; in any departure from these, we find it important to attend to the principles outlined on p. 1719, and particularly to calculate beforehand the range of hydration of the sulphuric acid during the proposed iodylation.

25 Millimols. of iodine pentoxide (= 8·38 g. of 99·4% material) are dissolved in 5·0 c.c. of water, and the solution is added to 20 c.c. of 95% sulphuric acid, a fine suspension thus being obtained. This is cooled, and is well shaken with 100 millimols. of pure chlorobenzene (*ca.* 10·3 c.c.), the temperature being 15—20°. With continual shaking, 30 c.c. more of the same sulphuric acid are run in from a burette in 2 c.c. doses, the temperature being kept between 15° and 25° by external cooling; this addition necessarily occupies some hours, but might be accelerated if a very efficient internal cooling arrangement were used. During the addition the mixture becomes very dark, the pentoxide eventually disappears, and the reaction is then over. To the mixture, chilled in a freezing mixture, are added 150 g. of chilled pure ice, in order to make the sulphuric acid about 8N. From this point, the treatment varies according to the object of the experiment, but it must be adapted to the somewhat inconvenient properties of iodonium salts, and to the presence of the by-product, the aromatic iodo-compound.

An oil deposits which crystallises on standing, and should then be crushed under its liquor. The crystals contain about nine-tenths of the total iodonium yield, and consist of anhydrous $R_2I{\cdot}HSO_4$ with some intermixed *p*-chloroiodobenzene, coloured dark by small traces of other substances. The solid is collected on a sintered-glass filter and washed free from iodic acid, if any is left, with 8N-sulphuric acid. To isolate the hydrogen sulphate as such, it must be washed free from water, acid, and the by-product by being rubbed repeatedly on the filter with dry ether, water vapour from the air and water-pump being excluded by appropriate fittings. Chloroform should not be used, for reasons only discovered at a late stage of our work; benzene may be used, if preceded by sufficient ether. For the final cleaning of the yield, a little dry acetone is advantageous. The best yields are *ca.* 14—15 g. From the filtrate and acid washings, the remaining iodonium is precipitable as iodide by aqueous hydriodic acid or sodium iodide, with the help of sulphur dioxide if necessary. The results of working up the final aqueous filtrate and the organic extracts (which have both been extensively studied) have been sufficiently outlined above; apart from pure *p*-chloroiodobenzene (about 2·5 g.), the extractable organic residues were insignificant—they yielded with alkali rose-purple phenolic substances, and may have contained isomeric chloroiodo-compounds.

The quantities obtained in one such operation (in which, however, chloroform had been used as well as ether for washing the crystals) were:

Millimols. Taken: I_2O_5, 24·9; H_2SO_4, 919; C_6H_5Cl, 97·0; H_2O, 460		Yields, %. On PhCl taken.	Yields, %. On I taken.
Obtained: $(C_6H_4Cl)_2I^{\cdot}$, in crystals	31·9	74·3	72·3
,, , from soln.	4·1		
p-$Cl{\cdot}C_6H_4{\cdot}I$	10·8	11·1	21·6
Free I_2	1·0	—	4·0
Totals:		85·4	97·9

Methods and Results of Analyses.—The aqueous solubilities of the nitrates, sulphates, etc., of some of the substituted iodonium radicals are so slight, even in hot water, that exceptional care has to be used in simple precipitations in order to ensure complete reaction and the purity of the precipitate. This applies to precipitations either of the iodonium as iodide, or of the anion with $Ag^{\cdot}$, $Ba^{\cdot\cdot}$, etc. It cannot be assumed, without prior disproof, that a given iodonium salt $R_2I{\cdot}X$ will not undergo some fission to RI and products representing RX when it is treated with warm reagents. Upon this change is based one method of determining the equivalent weight of an iodonium radical, the salt being boiled with standard alkali, of which the residual excess, including the phenoxide, is then titrated. Other methods for determining the iodonium radical as its iodide are as described in our former paper, supplemented in some cases by determinations as chloride gravimetrically. In determining total chlorine and iodine in a chlorophenyliodonium salt, the decomposition by Stepanow's method (a twelve-fold excess of sodium being used) is followed by the usual determination of total halogen in one part of the filtrate, and in the other, the iodide is separately determined by titration with standard iodate in 5N-sulphuric acid containing acetone with starch as indicator (Berg, *Z. Anal. Chem.*, 1926, **69**, 369), the accuracy of which for our compounds we have tested and found highly satisfactory. The methods of micro- or semi-micro-analysis would at present appear to be somewhat less

reliable for the halogens of these iodonium salts than are the foregoing full-scale methods, upon which alone we have therefore depended.

Product.	$(C_6H_4Cl)_2I\cdot HSO_4$. Found.	Calc.	$[(C_6H_4Cl)_2I]_2SO_4$. Found.	Calc.	$(C_6H_4Cl)_2I\cdot I$. Found.	Calc.	$C_6H_4Cl\cdot I$. Found.	Calc.
Total I	28·27	28·39	31·94	31·90	54·01	53·24	52·84	53·24
„ Cl	15·84	15·86	17·60	17·82	14·72	14·87	14·89	14·87
Ions: $R_2I^{\cdot}$.........	78·86	78·28	87·96	87·94	—	—	—	—
$H^{\cdot}$	0·228	0·226	—	—	—	—	—	—
SO_4''	21·73	21·48	12·05	12·07	—	—	—	—
I'	—	—	—	—	26·75	26·62	—	—

The iodonium iodide formed from the hydrogen sulphate or from the sulphate was that of which the analyses are shown in col. 6, and was wholly identical with the iodide precipitated from the iodylation filtrate whence the hydrogen sulphate had crystallised. Col. 8 gives the analysis of the product of its complete thermal decomposition in a sealed tube. The orientation was proved by the m. p. of this solid chloroiodobenzene after its dissolution in alcohol (to free it from a trace of iodine) and complete recovery and drying: m. p. 52·9°; synthetic *p*-chloroiodobenzene, m. p. 52·1°; mixed m. p. 52·3°. The chloroiodobenzene obtained as a by-product of iodylation had m. p. 51·2°, mixed m. p. 50·7°.

Action of Iodous Sulphate on Chlorobenzene.—In one of several experiments, iodine and iodine pentoxide in nearly theoretical proportion were first allowed to interact in sulphuric acid of composition $1\cdot99H_2SO_4 : H_2O$, in which they form a solid sulphate of the trioxide; this reaction has been described in outline by one of us (*Nature, loc. cit.*), and details will be published later. When this had occurred, and without separation of any of the ingredients, a minute excess of chlorobenzene was added, and the whole was sealed up and shaken on a wheel at 0° for 2 hours, and then kept overnight at 0°. The reaction mixture was worked up quantitatively by the methods described for iodylations, the products were identified by analyses and, as to orientation, by mixed m. p., as before, and the results were:

Taken: I_2, 0·513 g. = 2·02 millimols.;
I_2O_5, 1·005 g. of 98·8% = 2·97 millimols.
calculated to form
I_2O_3,4·95 millimols.; I_2, 0·035 millimol. (excess).

	Millimols.	Yield, %, on calc. I_2O_3.	
Obtained: $(C_6H_4Cl)_2I^{\cdot}$, in crystals	7·99	91·6	96·1
„ , from soln.	1·08		
p-$C_6H_4Cl\cdot I$	0·45	4·5	

Since in any case the preliminary formation of iodous sulphate from the initial reagents is, in this particular acid medium, not quite quantitative, whereas the above yields of iodonium, etc., are nevertheless calculated as if it were, it is clear that we have to do with an iodonium-forming reaction of very satisfactory completeness.

Addendum (*Received, September 23rd,* 1937).—Meyer and Wachter (*Ber.*, 1892, **25**, 2632), in describing iodosobenzoic acid, the first iodoso-compound, include the following passage which had escaped our notice: " Ferner ist zu prüfen, ob man durch Behandlung von aromatischen Substanzen mit Schwefelsäure und Jodsäure—JO_2OH, entsprechend der Reaction der Salpetersäure NO_2OH—Verbindungen mit der Gruppe -JO_2 erhalten kann. Wir können vorläufig nur mittheilen, dass Benzol beim Zusammenbringen mit Jodsäure und Schwefelsäure äusserst heftig reagirt und auf Zusatz von Wasser einen festen Körper abscheidet, welchen wir noch näher untersuchen werden."

It does not appear that the experiment was followed up either then or after 1894, when the iodoxy- and the iodonium group were discovered; but we should not like to omit reference to this early trial of the same idea which initiated our own work described in this and in our previous paper.

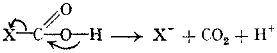
University of Durham (Durham Division).
[*Received, September 1st,* 1937.]

362. *Experiments on the Mechanism of Decarboxylation. Part I. Decomposition of Quinaldinic and* iso*Quinaldinic Acids in the Presence of Compounds containing Carbonyl Groups.*

By P. Dyson and D. Ll. Hammick.

When quinaldinic and *iso*quinaldinic acids are heated with excess of certain aldehydes and ketones (benzaldehyde, anisaldehyde, acetophenone), carbon dioxide is evolved and products are obtained which indicate that the decarboxylation takes place in accordance with the scheme *A* (below), where X is the quinolyl or *iso*quinolyl radical and Y and Z may be aryl, alkyl or hydrogen.

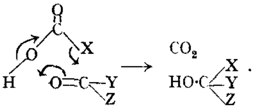
A mechanism for the loss of carbon dioxide from a carboxyl group is



if provision can be made in the reacting system for the stabilisation of the free radical X^- and the proton H^+ by subsequent (or simultaneous) reaction. In the preliminary experiments here described, such provision has been made by causing the decarboxylation of quinaldinic and *iso*quinaldinic acids to occur in the presence of excess of substances containing the carbonyl group (benzaldehyde, anisaldehyde and acetophenone), which is known from its reactions, such as the formation of cyanohydrins (Robinson, *J. Soc. Dyers and Colourists*, 1934, 65), to be capable of the electromeric activation process $>C{=}O$. Under such conditions, the above mechanism might be expected to lead to the formation of carbinols, thus:

$$\frac{Y}{Z}{>}C{=}O + X^- + H^+ \longrightarrow \frac{Y}{Z}{>}C{<}\frac{X}{OH}$$

or, in one process,



(*A*)

(for aldehydes, Z = H)

The choice of quinaldinic and *iso*quinaldinic acids for the study of decarboxylation in the presence of carbonyl groups was determined by the fact that their structures are such that decomposition of the type suggested above might be expected to be facilitated by the inductive effect of the $\overset{+\!\!\longrightarrow}{C{=}N}$ linkages in their molecules.

In each case decarboxylation was brought about by boiling the acid in excess of the other reagent. As will be seen in the Experimental part, we have been able to isolate either the carbinol to be expected on the basis of the mechanism suggested above or its ketonic oxidation product. Thus from benzaldehyde we have obtained ***phenyl-2-quinolylcarbinol*** and ***phenyl*-1-iso*quinolylcarbinol***, and from acetophenone and quinaldinic acid we have isolated ***phenyl-2-quinolylmethylcarbinol***, $C_9H_6N{\cdot}CPhMe{\cdot}OH$. By the decomposition of quinaldinic acid in boiling anisaldehyde we were unable to obtain the expected anisyl-2-quinolylcarbinol, owing apparently to its ready oxidisability to the corresponding ***ketone***, which was the substance actually isolated. The unsubstituted phenyl-2-quinolylcarbinol is less readily oxidised to the ketone, though crystallisation from hydroxylic solvents in the presence of air converts it into phenyl 2-quinolyl ketone, m. p. 107°, identical with an authentic specimen (Besthorn, *Ber.*, **1906**, **39**, 2330). It appears to be quite stable in contact with non-polar solvents such as ligroin. The corresponding phenyl-1-*iso*quinolylcarbinol is, on the other hand, comparatively stable in air and can be crystallised from any suitable solvent.

The conclusion we draw from these preliminary experiments is that the decarboxylation mechanism put forward above is in accordance with the facts observed when quinaldinic and *iso*quinaldinic acids are decomposed in certain aldehydes and ketones at their boiling points. Experiments are in hand to ascertain the generality of this type of reaction.

Experimental.

Quinaldinic Acid and Benzaldehyde. Preparation of Phenyl-2-quinolylcarbinol and of Phenyl 2-Quinolyl Ketone.—Quinaldinic acid (5 g.) was boiled with freshly distilled benzaldehyde (40 g.) in a 100 c.c. flask fitted with an air condenser until carbon dioxide was no longer evolved (2—3 hours). The mixture was poured into water, acidified with hydrochloric acid, and separated from the excess of benzaldehyde. After extraction with ether to remove traces of aldehyde and other impurities, the acid solution was made alkaline with sodium hydroxide. The oil that separated was taken up in ether and dried with anhydrous sodium sulphate. The oil remaining after the removal of the ether was dissolved in light petroleum (b. p. 40—60°) and left overnight in the ice chest. The colourless crystals (2·2 g.) that separated were recrystallised from light petroleum (b. p. 49—60°); m. p. 50—60°. Yield, 33% (Found: C, 81·8; H, 5·3. $C_{16}H_{13}ON$ requires C, 81·7; H, 5·5%).

The above reaction, carried out in a stream of nitrogen, gave a yield of 42%.

All attempts to prepare derivatives of this *carbinol* failed owing to the readiness with which it is oxidised to phenyl 2-quinolyl ketone (2-benzoylquinoline).

Quinaldinic Acid and Anisaldehyde. Preparation of Anisyl 2-Quinolyl Ketone.—Quinaldinic acid (5 g.) was refluxed for 3 hours with freshly distilled anisaldehyde (40 g.); evolution of carbon dioxide had then ceased. The product was worked up exactly as above for the reaction with benzaldehyde. Instead, however, of the corresponding carbinol we obtained *anisyl 2-quinolyl ketone* (0·72 g.), which formed colourless needles, m. p. 78°, after two recrystallisations from light petroleum (b. p. 40—60°); yield, 10%. The yield was increased to 30% (1·5 g. of the ketone from 5 g. of quinaldinic acid) by carrying out the reaction in a stream of nitrogen (Found: C, 77·8; H, 4·9. $C_{17}H_{13}O_2N$ requires C, 77·6; H, 4·9%). The 2 : 4-*dinitrophenylhydrazone* had m. p. 242° (Found: C, 62·6; H, 4·0. $C_{23}H_{17}O_5N_5$ requires C, 62·3; H, 3·8%). The picrate, precipitated from ethereal solution and recrystallised from water, had m. p. 165°. The oxime was prepared by refluxing 0·263 g. of the ketone (1 mol.), 0·08 g. of hydroxylamine hydrochloride (1·1 mols.), and 0·1 g. (1·25 mols.) of anhydrous sodium acetate in 10 c.c. of 50% aqueous alcohol for 2½ hours. It separated on dilution with water and was crystallised first from aqueous alcohol and finally from benzene; m. p. 145°.

Quinaldinic Acid and Acetophenone. Preparation of Phenyl-2-quinolylmethylcarbinol.—Quinaldinic acid (5 g.) was refluxed for 3 hours with freshly distilled benzophenone (40 g.), and the product worked up as before. The *carbinol* separated as colourless crystals from the ethereal extract and was recrystallised from light petroleum (b. p. 40—60°). Yield, 1·58 g. (32%); m. p. 100° (Found: C, 81·5; H, 6·1; N, 5·6. $C_{17}H_{15}ON$ requires C, 81·6; H, 6·0; N, 5·6%). The picrate, obtained from ethereal solution and recrystallised twice from water, had m. p. 169° (decomp.).

iso*Quinaldinic Acid and Benzaldehyde. Preparation of Phenyl-*1-iso*quinolylcarbinol and Phenyl* 1-iso*Quinolyl Ketone.*—*iso*Quinaldinic acid (2 g.) was refluxed with freshly distilled benzaldehyde (10 g.), evolution of carbon dioxide ceasing after 2 hours. The product, worked up as in the preceding experiments, separated from the ethereal extract as an oil which solidified on standing (1·14 g.; yield 57%); it had m. p. 106° after two recrystallisations from light petroleum (b. p. 40—60°) (Found: C, 81·9; H, 5·7; N, 6·1. $C_{16}H_{13}ON$ requires C, 81·7; H, 5·5; N, 6·0%). The *benzoyl* derivative, obtained by shaking the carbinol (0·14 g.) and benzoyl chloride (0·11 g.) in 5 c.c. of 2N-sodium hydroxide for 3 hours, had m. p. 158—159° after recrystallisation from 50% aqueous alcohol (Found: C, 80·8; H, 5·2. $C_{23}H_{17}O_2N$ requires C, 81·4; H, 5·0%).

A solution of the carbinol (0·23 g.) in 5 c.c. of 50% aqueous acetic acid containing 0·1 g. of potassium dichromate was kept at room temperature with occasional shaking for 24 hours. The ketone separated on dilution with water and after drying was crystallised from light petroleum (b.p. 40—60°); m. p. 76—77° (Kaufmann, *Ber.*, 1914, **47**, 2935) (Found: C, 82·7; H, 5·0. Calc. for $C_{16}H_{11}ON$: C, 82·4; H, 4·7%).

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The Dyson Perrins Laboratory, Oxford. [*Received, September 22nd*, 193?.]

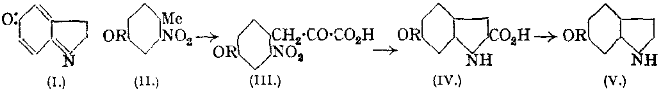
363. *The Synthesis of 5- and 6-Benzyloxyindoles and Attempts to prepare 5- and 6-Hydroxyindoles therefrom.*

By HAROLD BURTON and JOHN L. STOVES.

The synthesis of 5- and 6-benzyloxyindoles has been accomplished. Debenzylation gave, not the corresponding hydroxy-derivatives, but dark-coloured, complex, phenolic, amorphous substances, apparently formed by oxidative polymerisation.

THE knowledge that 5 : 6-dihydroxyindole (Dulière and Raper, *Biochem. J.*, 1930, **24**, 239) and 5 : 6-dihydroxy-1-methylindole (Burton, J., 1932, 546) undergo atmospheric oxidation in weakly alkaline solution to yield black melanin-like pigments, coupled with the lack of knowledge concerning the mechanism of such oxidations, led us to attempt the preparation of the simpler 5- and 6-hydroxyindoles, in order to see if they could be similarly oxidised to analogous pigments. It was foreseen that 5-hydroxyindole might undergo preferential oxidation to the quinonoid derivative (I), and for that reason it was decided to investigate the isomeric 6-derivative, since its structure precludes such a change.

In view of the well-known fact that the benzyl group can be eliminated much more readily than the methyl group from the respective phenolic ethers, the procedure finally adopted was to synthesise the benzyloxyindoles by methods similar to those used by Blaikie and Perkin (J., 1924, **125**, 307) for the methoxyindoles. Thus, *2-nitro-4-benzyloxytoluene* (II), condensed with ethyl oxalate in presence of potassium ethoxide, gave *2-nitro-4-benzyloxyphenylpyruvic acid* (III) together with a considerable amount of *2 : 2'-dinitro-4 : 4'-dibenzyloxydibenzyl* (for analogous results, compare Reissert, *Ber.*, 1897, **30**, 1052). Reduction of the pyruvic acid with ferrous hydroxide afforded *6-benzyloxyindole-2-carboxylic acid* (IV), which was decarboxylated to *6-benzyloxyindole* (V) by heating in glycerol. 2-Nitro-5-benzyloxyphenylpyruvic acid (Burton and Stoves, this vol., p. 403) similarly gave *5-benzyloxyindole-2-carboxylic acid* and thence *5-benzyloxyindole*, which, like its isomeride (V), has only feebly basic properties.



(I.) (II.) (III.) (IV.) (V.)

($R = CH_2Ph$)

Attempts to debenzylate either benzyloxyindole with hydrobromic or hydriodic acid in the customary manner resulted in the formation of dark-coloured complex substances, which, however, usually had phenolic properties. Furthermore, since the nitrogen content was only 45—60% of the theoretical value for the simple hydroxyindole, it would appear that these complex substances were produced by oxidative polymerisation of the first-formed hydroxyindoles; their molecular weights could not be determined, owing either to insolubility or to decomposition (as, for example, in camphor). Oxidation could be suppressed to some extent during debenzylation by working as far as possible in an atmosphere of nitrogen, but even then polymeric products were obtained. The hydroxyindoles containing the hydroxy-group in the benzene ring are, as regards instability, in marked contrast to those substituted in the pyrrole nucleus.

EXPERIMENTAL.

2-Nitro-4-benzyloxytoluene (II).—A mixture of 2-nitro-*p*-cresol (100 g.), benzyl chloride (84 g.), sodium hydroxide solution (27·5 g. in 200 c.c. of water), and alcohol (600 c.c.) was boiled under reflux for 8 hours. Removal of the alcohol by distillation and addition of water to the residue gave an oil which gradually solidified. Recrystallisation from benzene–ligroin gave 100 g. of *2-nitro-4-benzyloxytoluene* in nearly colourless, fine needles, m. p. 52° (Found: C, 69·1; H, 5·3; N, 5·9. $C_{14}H_{13}O_3N$ requires C, 69·1; H, 5·35; N, 5·8%).

2-Nitro-4-benzyloxyphenylpyruvic Acid (III).—Potassium ethoxide (from powdered potassium, 4·9 g., and sodium-dried alcohol, 5·7 g.) in ether (200 c.c.) was treated with ethyl oxalate (19·3 g.) and then with 2-nitro-4-benzyloxytoluene (30·3 g. in the minimum amount of ether). The mixture was heated under reflux for 18 hours and then treated with water. The yellow solid (*A*) obtained was collected and washed with a little ether, and the filtrate separated; evaporation of the dried (sodium sulphate) ethereal extract gave 8·4 g. of recovered nitrobenzyloxytoluene, and acidification of the aqueous extract with concentrated hydrochloric acid (Congo-red) afforded 14·1 g. of *2-nitro-4-benzyloxyphenylpyruvic acid*, which separated from water in pale yellow needles, m. p. 89—90°, apparently containing water of crystallisation (Found: C, 57·3; H, 4·8; N, 4·3. $C_{16}H_{13}O_6N,H_2O$ requires C, 57·6; H, 4·5; N, 4·2%). The acid gave a deep green coloration with alcoholic ferric chloride.

Recrystallisation of (*A*) from glacial acetic acid afforded material, m. p. 162°, which gave a deep purple colour with aqueous potassium hydroxide; two further recrystallisations from the same solvent afforded pale yellow plates, m. p. 164—165° (unchanged by further recrystallisation), which did not give a colour with potassium hydroxide. The substance is probably *2 : 2'-dinitro-4 : 4'-dibenzyloxydibenzyl* (Found: C, 69·1; H, 5·0; N, 6·0; *M*, in camphor, 507. $C_{28}H_{24}O_6N_2$ requires C, 69·4; H, 5·0; N, 5·8%; *M*, 484).

The use of sodium ethoxide as the condensing agent gave a tarry product from which the above acid could not be isolated.

6-Benzyloxyindole-2-carboxylic Acid (IV).—A hot solution of hydrated ferrous sulphate (156 g.) in water (300 c.c.) was added rapidly with stirring to a solution of 2-nitro-4-benzyloxypyruvic acid (26 g.) in sodium hydroxide (52 g. in 300 c.c. of water). The black mixture was heated (stirring) on the steam-bath for 1 hour and then boiled gently for ½ hour. Filtration of the iron oxide sludge and acidification of the concentrated filtrate with hydrochloric acid (Congo-red) gave 15 g. of *6-benzyloxyindole-2-carboxylic acid*, which separated from benzene in nearly colourless, ill-defined crystals, m. p. 185—186° (decomp.) (Found: C, 71·9; H, 4·8; N, 5·8. $C_{16}H_{13}O_3N$ requires C, 71·9; H, 4·9; N, 5·2%). The acid gave a red colour when warmed with Ehrlich's reagent.

5-Benzyloxyindole-2-carboxylic acid, similarly prepared from 2-nitro-5-benzyloxypyruvic acid (this vol., p. 403), could not be obtained pure. It crystallised from benzene in nearly colourless prisms, m. p. 190° with darkening, containing approximately $1H_2O$ (Found: C, 68·4; H, 5·2; loss at 110°, 9·0. $C_{16}H_{13}O_3N,H_2O$ requires C, 67·4; H, 5·3; H_2O, 6·3%), and gave a deep pink colour with Ehrlich's reagent.

6-Benzyloxyindole (V).—Attempted decarboxylation of 6-benzyloxyindole-2-carboxylic acid by heating alone, or in quinoline with or without copper-bronze, resulted in the production of unworkable tars. The following method proved fairly satisfactory. The acid (2·5 g.), mixed with glycerol (20 c.c.), was heated at 210° until gas evolution ceased. The cooled mixture was poured into water and extracted three times with ether. The residue from the washed and dried (sodium sulphate) ethereal solution was a dark brown tar, which was repeatedly extracted with light petroleum. Concentration gave colourless plates of *6-benzyloxyindole*, m. p. 111—112°, unchanged by further recrystallisation (Found: C, 80·9; H, 6·0; N, 6·0. $C_{15}H_{13}ON$ requires C, 80·7; H, 5·8; N, 6·3%), which gave with cold Ehrlich's reagent a transient red colour, becoming bluish-purple on heating. The yield was 4 g. from 15 g. of the acid.

5-Benzyloxyindole, similarly prepared (yield, 3 g. from 15 g. of 5-benzyloxyindole-2-carboxylic acid), separated from light petroleum in colourless fine needles, m. p. 96—97° (Found: C, 80·3; H, 6·0; N, 6·4. $C_{15}H_{13}ON$ requires C, 80·7; H, 5·8; N, 6·3%), which gave a reddish-purple colour with Ehrlich's reagent (cold or hot). Both benzyloxyindoles darkened gradually when kept. They did not yield picrates, but formed unstable hydriodides.

5-Benzyloxy-1-acetylindole, obtained when the indole (3 g.) was boiled with acetic anhydride (40 c.c.) and sodium acetate (10 g.) for 3 hours, separated from methyl alcohol in nearly colourless, prismatic needles, m. p. 129—130° (Found: C, 77·3; H, 5·6. $C_{17}H_{15}O_2N$ requires C, 77·0; H, 5·7%).

Attempts to prepare 6-Hydroxyindole.—(i) 6-Benzyloxyindole (1 g.), acetic acid (10 c.c.), and 48% hydrobromic acid (10 c.c.) were heated on the steam-bath for 5 hours, the colour of the mixture changing through red to green; volatile products were then removed as far as possible by steam-distillation. Filtration of the residue removed a small amount of brown solid (insoluble in sodium hydroxide solution), and neutralisation of the filtrate with sodium bicarbonate precipitated a dark red solid (Found: N, 6·4. C_8H_7ON requires N, 10·5%), which was soluble in alcohol and sodium hydroxide solution.

(ii) A mixture of the benzyl ether (1 g.), acetic acid (20 c.c.), and hydriodic acid (d 1·7;

20 c.c.) was kept at room temperature for 24 hours, then diluted with water, and finally neutralised with sodium bicarbonate, whereupon considerable darkening occurred. Extraction with ether and subsequent filtration of the aqueous residue gave a dark-brown solid, soluble in alcohol and sodium hydroxide solution, which gave a red colour with Ehrlich's reagent. A trace only of phenolic material was removed from the above ethereal extract by sodium hydroxide.

(*iii*) A mixture of 6-benzyloxyindole (1 g.), acetic acid (20 c.c.), and a 54% solution of hydrogen bromide in acetic acid (10 c.c.) was heated on the steam-bath for 15 minutes and, after dilution with air-free water, was distilled until free from benzyl bromide; all the operations were carried out in an atmosphere of nitrogen. The hot solution was filtered from a little tar, and the residual hydrobromic acid removed with solid sodium acetate, whereupon an orange-brown solid (*B*) (Found: N, 7·6%) was precipitated. Neutralisation of the filtrate with sodium bicarbonate gave a small amount of a similar precipitate (Found: N, 8·9%). Solid (*B*) was only slightly soluble in hot acetic acid; it dissolved in aqueous sodium hydroxide to a brick-red solution which gradually turned brown, and with Ehrlich's reagent in the hot gave a reddish-violet colour which subsequently became green.

Attempts to prepare 5-Hydroxyindole.—(i) A mixture of 5-benzyloxyindole (1 g.), acetic acid (20 c.c.), and hydriodic acid (*d* 1·7; 20 c.c.) was heated on the steam-bath for 15 minutes and then steam-distilled until free from benzyl iodide. Filtration of the residue removed an amorphous black solid (Found: N, 4·7%), which dissolved in aqueous sodium hydroxide to a brown solution; neutralisation (sodium bicarbonate) of the filtrate gave a grey precipitate (Found: N, 4·9%), also soluble in aqueous sodium hydroxide to a dark green solution.

(ii) The experiment was carried out as under (iii) (above). Removal of the excess of hydrobromic acid with solid sodium acetate precipitated a small amount of a dark brown solid (Found: N, 5·5%), and subsequent neutralisation (sodium bicarbonate) also gave a brown solid (Found: N, 9·0%) as the major product. Both solids dissolved in aqueous sodium hydroxide, yielding brown solutions.

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364. *Structure of Benzene. Part X. Remarks on the Intensities of the Raman Lines in Benzene and Hexadeuterobenzene.*

By R. C. Lord, junr., and E. Teller.

This paper deals with the theory of the effect of isotopic substitution on the intensities of Raman lines and infra-red absorption bands. In Parts III and IV quite irregular changes of intensity were found on passing from C_6H_6 to C_6D_6. They are now explained and the theory is quantitatively illustrated with respect to Raman intensities for which the experimental measurements have quantitative significance.

It is shown to be necessary for the calculation of intensity changes to consider collectively the dynamically inter-related vibrations of a symmetry class, including in each class any rotation thereto belonging, since, in general, rotations as well as vibrations can change the dipole moment vector and the polarisability tensor, on the variations of which absorption and scattering respectively depend.

The intensity changes in the A_{2u} infra-red vibration (relative parallel displacements of carbon and hydrogen hexagons along the six-fold axis), the two A_{1g} Raman vibrations (symmetrical expansion and contraction frequencies) and the E_g^- Raman vibration (relative rotation of carbon and hydrogen hexagons about a common axis in the ring-plane) are calculated in detail. The reason why the last, the only vibration of its class, gives rise to a stronger Raman line in C_6D_6 although the vibration amplitude must be smaller (a difficulty mentioned in Part III) is that the symmetry class includes a rotation. The effect of this rotation upon the variation in polarisability is taken into account in calculating the intensity change. The calculated intensities (and polarisations) agree well with experiment.

1. *General Remarks.*—The data of Angus, Ingold, and Leckie (Part III, J., 1936, 925) on the intensities and polarisations of the Raman lines in benzene and hexadeuterobenzene

furnish a means of testing quantitatively the general theory of intensities in the Raman effect. The infra-red absorption of these compounds has likewise been investigated (Bailey, Hale, Ingold, and Thompson, Part IV, J., 1936, 936), but since experimental absorption intensities in general have only qualitative significance, our discussion will be confined almost wholly to the Raman effect.

A glance at both the Raman and the infra-red data reveals a pronounced irregularity in the intensity changes produced by substitution of deuterium for hydrogen in benzene. In the infra-red, for example, the benzene frequency at 1485 cm.$^{-1}$ ($E_u^{-(c)}$) is of the same high intensity as the other active fundamentals, whereas in hexadeuterobenzene the corresponding band at 1333 cm.$^{-1}$ has become so weak that it is of the same intensity as several combination bands in its neighbourhood. The remainder of the active frequencies, on the other hand, exhibit about equal intensities in the two compounds. In the Raman effect, the 849 cm.$^{-1}$ line in benzene (E_g^-) is 35% *less* intense than the cognate line in hexadeuterobenzene, while the totally symmetrical ring vibration ($A_{1g}^{(c)}$) has about the same strength in both compounds. The two degenerate ring frequencies ($E_g^{+(c)}$), on the contrary, exhibit marked intensity decreases in hexadeuterobenzene.

Such irregularity is not surprising when one considers that the various Raman lines and infra-red bands arise from different modes of molecular vibration. The changes in polarisability α and in electric moment M of the molecule, which determine respectively the intensities of the molecule's Raman scattering and infra-red absorption, are directly dependent on the vibration forms. The several vibration forms may be altered variously by isotopic substitution, and in consequence the effect of substitution on intensities in the Raman effect and infra-red may differ considerably from one vibration type to the next. Investigation of the modes of vibration and of the functional dependence of α and M upon them is therefore a prerequisite to the determination of intensity relationships in isotopically related molecules.

This investigation is simple only for such normal vibrations as are alone in their symmetry classes, because the form of these vibrations is determined by symmetry. In most polyatomic molecules, however, nearly every vibration form has to share a symmetry class with one or more of the other forms. In benzene, for example, two modes share symmetry class A_{1g} (see Part VIII, J., 1936, 971), four share class E_g^+, two class E_u^+ and so on. Whenever several modes possess a common symmetry, these modes are dynamically inter-related, with the result that the amplitudes and frequencies of vibration cannot be calculated for each mode independently of the others, but rather must be calculated simultaneously for the entire class of modes. Since α and M depend on the amplitudes of vibrational motion, the intensities both of Raman scattering and of infra-red absorption due to vibration modes of a given symmetry class must also be inter-related. In studying intensity changes produced by isotopic substitution, we are thus compelled to consider changes in an entire class rather than in individual lines or bands.

It should be stated that one may also classify the various translational and rotational forms of molecular motion according to their symmetry properties, and in addition, that translation and rotation may share their symmetry classes with one or more vibration forms. The calculation of isotopic intensity shifts for such communal symmetry classes must then involve a consideration of the dependence of α and M on translation and rotation. Translation does not influence either α or M. Rotation, on the other hand, has a well-known effect on these quantities, so that the presence of a rotational type of motion in any symmetry class must be taken into account in the determination of the intensity relationship in that class.

The vibrational type A_{2u} affords the simplest illustration of the foregoing discussion. This mode is infra-red-active, and to its symmetry class belongs only one other type of motion (translation along a line normal to the ring plane), which does not affect our discussion of intensities. We have therefore only to consider the relative changes in the M's due to this vibration in benzene and hexadeuterobenzene. The intensities are proportional to the squares of these changes. The changes in M are proportional to the amplitudes of vibration, which are in turn proportional to the square roots of the frequencies. The intensities should thus be in the same ratios as the frequencies, *i.e.*, 671 : 503. Actually

this band appears, from the extinction coefficients, to be weaker in hexadeuterobenzene by about one-third, but as we have remarked, data on infra-red absorption intensities ordinarily have little quantitative significance.

2. *Intensity Change in Class* E_g^-.—The doubly degenerate Raman-active frequency of symmetry E_g^- offers a somewhat more complicated problem. In discussion with Professor Ingold one of us (E. T.) suggested that this frequency should have an intensity in hexadeuterobenzene lower than that in benzene by a factor equal to the ratio of the frequencies (Part VIII, *loc. cit.*). An intensity shift of this size and direction should certainly be expected if the vibration E_g^- were alone in its class. The degenerate vibration, however, shares the class with a "doubly degenerate" rotation, and the intensity discussion must take the latter into account.

The motion of class E_g^- consists of rotation of the carbon ring and of the hydrogen ring about a common axis, which may be either of two mutually perpendicular axes lying in the plane of the rings. If the carbon and hydrogen hexagons rotate in the same direction and through the same angle, the motion is a pure rotation. If the rings move in opposite directions so that the sum of their angular momenta is zero, the motion is vibrational (Part VIII, Fig. 1). The rotation of the two rings produces a distortion of α which leads to the presence of the vibration in the Raman effect. Let us call the magnitude of this distortion $\Delta\alpha$.

The intensity of Raman scattering is proportional to $(\Delta\alpha)^2$. We are interested in the ratio $(\Delta\alpha)^2/(\Delta\alpha')^2$. The prime (′) refers to hexadeuterobenzene. Our problem is to express $\Delta\alpha'$ in the terms of $\Delta\alpha$. To do this we remark that $\Delta\alpha$ may be regarded as the sum of two changes in polarisability, the one, $\Delta\alpha_H$, being caused by the rotation of the hydrogen ring when the carbon ring remains fixed, and the other, $\Delta\alpha_C$, caused by the rotation of the carbon ring with the hydrogen ring kept fixed. Thus

$$\Delta\alpha = \Delta\alpha_H + \Delta\alpha_C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

and for hexadeuterobenzene

$$\Delta\alpha' = \Delta\alpha'_H + \Delta\alpha'_C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1')$$

The ratio $\Delta\alpha_C/\Delta\alpha'_C$ is given by the ratio of the angular amplitudes of the carbon ring in the two vibrations, and $\Delta\alpha_H/\Delta\alpha'_H$ by the hydrogen–deuterium amplitude ratio. If these respective ratios were equal, $\Delta\alpha/\Delta\alpha'$ would also have the same value and we could say immediately *that the intensity in benzene should be larger by the square of the amplitude ratio.* Actually, the ratios are not the same, and we are compelled to consider the variation of $\Delta\alpha$ in detail.

The angle *between* the carbon and hydrogen rings at maximum amplitude is smaller in hexadeuterobenzene than in benzene by the factor $\sqrt{\nu'/\nu}$, but neither the carbon nor the hydrogen ring amplitudes in the respective compounds will be related by this factor. The carbon amplitude, in fact, increases in hexadeuterobenzene, whereas the hydrogen amplitude is somewhat less than $\sqrt{\nu'/\nu}$ of its value in benzene. For purposes of calculation, however, it is helpful to consider a *hypothetical* "vibration" of the hexadeuterobenzene molecule in which both the carbon and hydrogen amplitudes *are* related to those in benzene by the same factor $\sqrt{\nu'/\nu}$. During this hypothetical "vibration" angular momentum is not conserved. In order to get the real vibration for hexadeuterobenzene, we have to add to the hypothetical one a libration, *i.e.*, a rotation through a small angle about the axis of vibration. The amplitude of the libration is chosen so that the angular momentum of the resulting vibration is zero. The contribution of our hypothetical "vibration" to $\Delta\alpha'$ is obtained from $\Delta\alpha$ by multiplication with $\sqrt{\nu'/\nu}$. It remains then to determine the contribution of the libration.

The contribution of libration to $\Delta\alpha'$ is given by the product of the libration angle, $\Delta\phi$, and the change in α, the polarisability of the whole molecule, upon rotation through unit angle about an axis in the ring plane. We remark that the polarisability of the molecule may be represented, as usual, by an ellipsoid. This ellipsoid is ordinarily not a sphere. If it were, rotation would not affect it and the contribution of libration would vanish. The contribution thus arises only from the anisotropy of the polarisability ellipsoid, and since the anisotropy is readily determinable from the Rayleigh scattering of the molecule, we have a means of finding the contribution of molecular rotation to $\Delta\alpha'$.

The polarisation of Rayleigh scattering can be interpreted by resolving the polarisability ellipsoid into two independent ellipsoids, one spherical and the other anisotropic. The spherical ellipsoid contributes only to the polarised component of the Rayleigh scattering, whereas all of the *depolarised* scattering is due to the anisotropic ellipsoid. The anisotropy of the molecular polarisability may thus be found from the intensity of the depolarised component of the Rayleigh line. We need not know its absolute intensity, for we are interested only in the relative values of $\Delta\alpha$ and $\Delta\alpha'$. It is therefore sufficient to know the ratio of the Rayleigh intensity to the intensity of the Raman line under consideration. This ratio has been measured for benzene (Carrelli and Went, *Z. Physik*, 1932, **76**, 236), and since we may assume that the molecular polarisabilities of benzene and of hexadeuterobenzene are essentially equal, we may find the anisotropy of hexadeuterobenzene in terms of $\Delta\alpha$ from the intensity measurements on benzene.

The actual calculation of the librational contribution is carried out below. We cannot say in advance, however, whether libration will lessen or increase $\Delta\alpha'$, *i.e.*, whether the ratio of Raman intensities $(\Delta\alpha')^2/(\Delta\alpha)^2$ will be less or more than ν'/ν. The ratio would be ν'/ν if libration made no contribution. Let us illustrate by two models.

(1) Suppose the motion of the hydrogen ring has no influence on the molecular polarisability. Rotation of the carbon ring through a given angle should cause, accordingly, a rotation of the polarisability ellipsoid through the same angle. In this case the Raman intensity will be greater for hexadeuterobenzene by a factor of 2·13, because the carbon hexagon vibrates in hexadeuterobenzene through an amplitude which is $\sqrt{2{\cdot}13}$ times larger than the amplitude in benzene.

(2) Suppose, on the contrary, that the motion of the carbon ring does not influence the polarisability. The polarisability ellipsoid then should rotate with the hydrogen ring, and the intensity should be smaller in hexadeuterobenzene by the square of the deuterium–hydrogen amplitude ratio, *i.e.*, by the factor 0·533. The observed increase in intensity indicates qualitatively that the first model more nearly corresponds to the actual state of affairs in benzene.

To place the foregoing discussion on a quantitative basis, we put

$$\Delta\alpha' = \Delta\alpha\sqrt{\nu'/\nu} + \Delta\phi(\partial\alpha/\partial\phi) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

in which the last term is the contribution of libration. The angle of libration $\Delta\phi$ may be determined from

$$M_H\phi_H\sqrt{\nu'/\nu} + (2M_H + M_C)\Delta\phi = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where ϕ_H is the amplitude of the hydrogen ring in the benzene vibration, and M_H and M_C are the inertial momenta of the hydrogen and carbon hexagons around an axis lying in the plane of the hexagons.*

Equation (3) expresses the fact that the angular momentum of the actual hexadeuterobenzene vibration is zero, the first term giving the momentum of the hypothetical "vibration" and the second term the compensating momentum of the libration. From (2) and (3) we obtain

$$\frac{\Delta\alpha'}{\Delta\alpha} = \sqrt{\frac{\nu'}{\nu}}\left[1 - \frac{M_H}{2M_H + M_C}\cdot\frac{(\partial\alpha/\partial\phi)}{\Delta\alpha}\cdot\phi_H\right] \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

$\Delta\alpha$, $\Delta\alpha'$, and $(\partial\alpha/\partial\phi)$ represent tensors, and before proceeding we must explain what we mean by the quotient of two tensors. It follows from a symmetry argument that since $\Delta\alpha$, $\Delta\alpha'$, and $(\partial\alpha/\partial\phi)$ correspond to rotations through small angles about a common axis, they differ only by numerical factors. The quotients in (4) stand for the ratios of these numerical factors. For purposes of calculation it is simpler to find first the squares of these quotients, which we obtain when we replace each tensor by the sum of the squares of its components. These sums we denote by $(\Delta\alpha)^2$, $(\Delta\alpha')^2$, and $(\partial\alpha/\partial\phi)^2$ respectively.

Let us first calculate $(\partial\alpha/\partial\phi)^2$. If we select the six-fold axis of benzene as the z-axis, the principal values c_{xx}, c_{yy}, and c_{zz} of the polarisability tensor α may be denoted respectively by $\alpha_\perp$, $\alpha_\perp$, and $\alpha_\parallel$ (c_{xx} and c_{yy} are equal because of the symmetry of the benzene molecule).

* $2M_H$ is used for M'_H.

If the molecule is rotated through the small angle $\delta\phi$ from its original position, the rotation taking place about the x-axis, the original polarisability tensor (I) will be changed to (II):

$$\begin{vmatrix} \alpha_\perp & 0 & 0 \\ 0 & \alpha_\perp & 0 \\ 0 & 0 & \alpha_\parallel \end{vmatrix} \qquad \begin{vmatrix} \alpha_\perp & 0 & 0 \\ 0 & \alpha_\perp \cos^2\delta\phi & -(\alpha_\perp - \alpha_\parallel)\cos\delta\phi\sin\delta\phi \\ 0 & (\alpha_\perp - \alpha_\parallel)\cos\delta\phi\sin\delta\phi & \alpha_\parallel\cos^2\delta\phi \end{vmatrix}$$

(I.) (II.)

In order to find $(\partial\alpha/\partial\phi)^2$ we subtract (I) from (II), divide each component of the resulting tensor by $\delta\phi$, square, and take the sum. For $\delta\phi \rightarrow 0$, we obtain

$$(\partial\alpha/\partial\phi)^2 = 2(\alpha_\perp - \alpha_\parallel)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

We have previously remarked that the polarisability ellipsoid representing α may be *resolved into a spherical and an anisotropic part*:

$$\alpha = \alpha_{sp.} + \alpha_{an.}$$

The corresponding resolution of the tensor (I) is:

$$\begin{vmatrix} \alpha_\perp & 0 & 0 \\ 0 & \alpha_\perp & 0 \\ 0 & 0 & \alpha_\parallel \end{vmatrix} = \begin{vmatrix} \frac{2\alpha_\perp + \alpha_\parallel}{3} & 0 & 0 \\ 0 & \frac{2\alpha_\perp + \alpha_\parallel}{3} & 0 \\ 0 & 0 & \frac{2\alpha_\perp + \alpha_\parallel}{3} \end{vmatrix} + \begin{vmatrix} \frac{\alpha_\perp - \alpha_\parallel}{3} & 0 & 0 \\ 0 & \frac{\alpha_\perp - \alpha_\parallel}{3} & 0 \\ 0 & 0 & -2\frac{\alpha_\perp - \alpha_\parallel}{3} \end{vmatrix} \quad (6)$$

(I.) (Spherical.) (Anisotropic.)

From (5) and (6) we find

$$(\alpha_{an.})^2 = \tfrac{2}{3}(\alpha_\perp - \alpha_\parallel)^2$$

and

$$(\partial\alpha/\partial\phi)^2 = 3(\alpha_{an.})^2$$

The intensity of the anisotropic part of the Rayleigh scattering by benzene (*i.e.*, the depolarised part of the undisplaced line) is proportional to $(\alpha_{an.})^2$.

Let $\Delta\alpha$, $\Delta\alpha'$, and $\Delta\phi$ in equation (2) denote the matrix elements * of these quantities for the 0—1 vibrational transition; $(\Delta\alpha)^2$ is then proportional to the intensity of the Raman line arising from the 0—1 transition. The proportionality constants relating $(\alpha_{an.})^2$ and $(\Delta\alpha)^2$ to the intensities of the depolarised parts of the Rayleigh and of the Raman scattering respectively are the same. Therefore the ratio $(\partial\alpha/\partial\phi)^2/(\Delta\alpha)^2$ can be obtained from the experimentally determined intensity ratio of the Rayleigh to the Raman line in benzene. The depolarised part of the Rayleigh line is found by multiplying its total intensity by the factor $\Delta/(1 + \Delta)$, where Δ is the depolarisation factor of the undisplaced line. In the same way the ratio $\rho/(1 + \rho)$ (ρ is the Raman depolarisation factor) converts the total intensity of the Raman line into its depolarised portion. If we denote by I_0/I_r the ratio of total intensities of the Rayleigh and Raman lines scattered by benzene vapour, we may put

$$\frac{(\alpha_{an.})^2}{(\Delta\alpha)^2} = \frac{(\partial\alpha/\partial\phi)^2}{3(\Delta\alpha)^2} = \frac{\{\Delta/(1 + \Delta)\}I_0}{\{\rho/(1 + \rho)\}(I_r/2)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

I_r is divided by 2 because the double degeneracy of the Raman frequency in question has doubled I_r. Since we are considering the matrix element of $\Delta\alpha$ for the 0—1 transition, I_r is the Raman intensity observed at the absolute zero, at which temperature only the 0—1 transition can take place. I_r at 0° K. is found from the observed intensity by multiplying by the factor $(1 - \epsilon)$, where ϵ is $\exp(-h\nu/kT)$; ϵ is quite small ($\epsilon = 0.015$ at 290° K.), so this correction is not important. When we insert the temperature factor and rearrange, we obtain from (7)

$$\frac{(\partial\alpha/\partial\phi)}{\Delta\alpha} = \sqrt{\frac{6\Delta(1 + \rho)I_0}{\rho(1 + \Delta)I_r(1 - \epsilon)}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

* The matrix element of $\Delta\alpha$, for example, is a tensor whose components are the matrix elements of the components of $\Delta\alpha$ (cf. Placzek, *Leipziger Vorträge* 1931, pp. 74—75).

Having replaced $\Delta\alpha$ by its matrix element, we must follow the same procedure with $\Delta\phi$. Since, according to equation (3), $\Delta\phi$ is related to ϕ_H by a constant factor, we may express the matrix element of $\Delta\phi$ in terms of the matrix element of ϕ_H, a transformation which has been made implicitly in equation (4). The evaluation of the matrix element of ϕ_H is facilitated by noting that ϕ_H is related to the angle between the hydrogen and carbon rings at maximum amplitude, $\phi_H - \phi_C$, thus :

$$\phi_H = (\phi_H - \phi_C)M_C/(M_C + M_H)$$

The matrix element of ϕ_H is therefore equal to the matrix element of $\phi_H - \phi_C$ multiplied by $M_C/(M_C + M_H)$. For the transition from the nth vibrational state to state $n + 1$ we have

$$\left|\phi_H - \phi_C\right|_n^{n+1} = \sqrt{\frac{(n+1)h}{8\pi^2\mu\nu}}$$

in which μ refers to the reduced moment of inertia of the carbon and hydrogen rings, *i.e.*, $1/\mu = 1/M_C + 1/M_H$. The matrix element for the 0—1 transition will therefore be

$$\left|\phi_H\right|_0^1 = \frac{M_C}{M_C + M_H}\sqrt{\frac{h}{8\pi^2\mu\nu}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

When we denote by $\Delta\alpha'$ in equation (4) the matrix element of $\Delta\alpha'$ for the 0—1 transition, and square both sides of the equation, we obtain I'_ν/I_ν, the ratio of intensities of the Raman lines in hexadeuterobenzene and in benzene at 0° K. The substitution of (8) and (9) in (4) thus leads to

$$I'_\nu/I_\nu = (1 - \delta)^2\nu'/\nu \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

where
$$\delta = \frac{\mu}{2M_H + M_C}\sqrt{\left[\frac{6\Delta(1+\rho)I_0}{\rho(1+\Delta)I_\nu(1-\epsilon)}\right]\left[\frac{h}{8\pi^2\mu\nu}\right]}$$

I'_ν/I_ν must be converted into the ratio at 290° K. by multiplying I_ν by $1/(1 - \epsilon)$ and I'_ν by $1/(1 - \epsilon')$; ϵ' is $\exp(-h\nu'/kT)$. The temperature correction is, as before, unimportant.

For the numerical evaluation of δ we have adopted the following values: ortho-C–C distance in benzene, 1·40 A.; ortho-H–H distance, 2·48 A.; $\Delta = 0{\cdot}0445$; $\rho = 6/7$; $\nu = 848{\cdot}9$ *cm.*$^{-1}$; $\nu' = 661{\cdot}2$ *cm.*$^{-1}$.

A value for the intensity ratio I_0/I_ν for benzene vapour has been given by Carrelli and Went (*loc. cit.*). Their measurements were actually made with the liquid but have been converted by them to relate to the vapour. In their paper (Table 4, p. 248) they list the ratios in the gas of the whole Raman scattering to the isotropic (*i.e.*, polarised) part of the Rayleigh scattering for the various Raman-active frequencies. Since I_0 in our formula denotes the *entire* Rayleigh scattering, it is necessary to multiply their ratio for the 849 frequency by the factor $(1 - \frac{7}{6}\Delta)/(1 + \Delta)$. The value of Δ is that for the gas ($\Delta = 0{\cdot}0445$) and is not to be confused with Carrelli and Went's Δ_l, the depolarisation factor for the liquid. We obtain for the corrected ratio: $I_0/I_\nu = 3{\cdot}06 \times 10^4$.

Substitution of the foregoing numerical data in equation (10) leads to the value $\delta = \pm 0{\cdot}656$. The ratio I'_ν/I_ν corrected to 290° K. then becomes 0·095 for $+\delta$ and 2·18 for $-\delta$. The experimental ratio is 1·5. It is clear that we must take the negative sign for δ. The discrepancy between the calculated value 2·18 and the observed ratio is small enough to be due to experimental error in the measurements of I'_ν/I_ν or, more probably, of I_0/I_ν, particularly in view of the difficulty of measuring accurately the ratio of two intensities differing by a factor of thousands. It appears still more probable, however, that the discrepancy is due to uncertainty in the method of calculating the ratio I_0/I_ν in the vapour phase from intensities measured in the liquid. This is shown by the following discussion.

In order to find intensities in the vapour from those in the liquid, Carrelli and Went have assumed that the polarisabilities α and the vibrational changes in polarisability $\Delta\alpha$ are the same for the individual molecules both in the liquid and in the gas. This assumption is reasonable in the light of the experimental fact that Raman lines which are forbidden in the gas are observed

only very weakly or not at all in the liquid.* Even under this assumption, however, the calculation of intensities in the vapour is not unequivocal. Carrelli and Went's formula for the intensity ratio, I_v/I_t, of Raman to Rayleigh scattering in the liquid is

$$\frac{I_r}{I_t} = \frac{n^4}{\left(\frac{n^2+2}{3}\right)^2} \cdot \frac{1 - \frac{7}{6}\Delta_t}{1 + \Delta_t} \cdot \frac{1}{kT\beta N} \left[\left(\frac{\lambda'}{\lambda}\right)^4 \frac{(5A^2{}_{ss} + 13\gamma^2{}_{cs})/45}{(A_0/3)^2}\right] \quad . \quad . \quad (11)$$

in which the quantity in square brackets is the ratio of Raman scattering to polarised Rayleigh scattering by the vapour; n designates the refractive index of the liquid, β its compressibility, and N the number of molecules per c.c.

The factor $1/(kT\beta N)$ gives the density fluctuations which determine the Rayleigh scattering of the liquid, and the factor $(1 - \frac{7}{6}\Delta_t)/(1 + \Delta_t)$ reduces this scattering to its isotropic part. Such a reduction is necessary because the randomness of molecular orientation will give rise to an anisotropic scattering when the molecular polarisability is anisotropic. This anisotropic scattering is not due to density fluctuations and must be eliminated before the theory of density fluctuations can be applied to the calculation of Rayleigh scattering by the liquid. It is tacitly assumed in the derivation of equation (11) that only the isotropic part of the molecular polarisability contributes to the isotropic part of the Rayleigh scattering of the liquid. This assumption is not strictly valid, since the anisotropic part of the molecular polarisability may give rise, under the influence of anisotropic density fluctuations, to isotropic scattering.

The most uncertain feature of equation (11), however, is the coefficient $n^4/[(n^2 + 2)/3]^2$. This factor takes into account the effect of polarisation of the dielectric medium on scattering. In a liquid such as benzene, composed of non-spherically symmetric molecules, the electric field acting on an individual molecule will be strongly influenced both by the position and by the orientation of the dipoles which are induced in the surrounding molecules by the incident light wave. In general, there will be no simple expression for taking this influence into account. On the other hand, if the molecules are spherically symmetric (as in carbon tetrachloride) the principal effect of the polarisation of the dielectric will be the same both for Rayleigh and for Raman scattering, the only difference being that in the former there is also interaction between the additional induced dipoles which arise from density fluctuations. This interaction, however, will contribute only to the anisotropic part of the Rayleigh scattering, and has already been eliminated from consideration by the depolarisation term. The $n^4/[(n^2 + 2)/3]^2$ factor should therefore be replaced by unity for spherically-symmetric molecules.

If the $n^4/[(n^2 + 2)/3]^2$ factor is omitted for the calculation of I_0/I_v in benzene vapour, we find for this ratio $1{\cdot}22 \times 10^4$ rather than $3{\cdot}06 \times 10^4$. We then obtain $\delta = -0{\cdot}412$ and I'_v/I_v at 290° K. is 1·59, which is practically the measured value. In the absence of further information about the theory of liquids, the omission of the factor $n^4/[(n^2 + 2)/3]^2$ is no less justified than its inclusion. The uncertainty in the calculation of I'_v/I_v is therefore of about the same magnitude as the discrepancy with experiment. The whole matter could be cleared up by making accurate measurements of I_0/I_v in the vapour.

3. *Intensities of the Totally Symmetrical Frequencies.*—The above information concerning the relative importance of the carbon and hydrogen hexagons in determining $\Delta\alpha$ for the molecule may be used as a basis for qualitative statement about intensity relationships in the class A_{1g}. The amplitudes through which the carbon atoms move during the vibration $A_{1g}^{(c)}$ are slightly larger in benzene than in hexadeuterobenzene, while in $A_{1g}^{(H)}$ the carbon amplitudes are considerably greater in hexadeuterobenzene. We have found for the E_g^- vibration that $\Delta\alpha$ (and thus the intensity) is chiefly dependent on the motion of the carbon atoms: $A_{1g}^{(c)}$ should therefore be a little more intense, and $A_{1g}^{(H)}$ noticeably less intense, in benzene. Actually, both are about 2% more intense.

The carbon atoms participate very little in vibration $A_{1g}^{(H)}$, but have quite considerable amplitudes in $A_{1g}^{(c)}$. The latter frequency should therefore be the stronger both in benzene and in hexadeuterobenzene. Experimentally, the former is 6% more intense in both

* It must be borne in mind, however, that changes in $\Delta\alpha$ brought about by change of state may give rise to considerable intensity changes in allowed lines, even though changes in $\Delta\alpha$ for forbidden vibrations will result only in very small intensities in the liquid. For example, if $\Delta\alpha$ for a particular allowed vibration is 1·0 in the vapour and changes to 1·1 in the liquid, the intensity will change to 1·2 (*i.e.*, $1{\cdot}1^2$). On the other hand, if $\Delta\alpha$ for a forbidden vibration changes from zero in the vapour to 0·1 in the liquid, the intensity of the forbidden line in the liquid will be only 0·01.

compounds. This disagreement of experiment with our qualitative expectations indicates that the dependence of $\Delta\alpha$ on amplitude is less simple than we have assumed. It is thus essential to consider the amplitude and intensity relationships of the class A_{1g} in a quantitative manner.

In order to calculate the intensities of the totally symmetrical frequencies, we express the hexadeuterobenzene vibration $A_{1g}^{(c)\prime}$ in terms of a linear superposition of the benzene vibrations $A_{1g}^{(n)}$ and $A_{1g}^{(c)}$ by means of suitable coefficients ξ_1 and η_1 :

$$A_{1g}^{(c)\prime} = \xi_1 A_{1g}^{(n)} + \eta_1 A_{1g}^{(c)}$$

The detailed meaning of this symbolic equation is that

$$\left.\begin{aligned} \chi'_{1H} &= \xi_1\chi_{1H} + \eta_1\chi_{2H} \\ \chi'_{1C} &= \xi_1\chi_{1C} + \eta_1\chi_{2C} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

where χ'_{1H} and χ'_{1C} are the amplitudes of the hydrogen atoms and of the carbon atoms respectively in the hexadeuterobenzene vibration $A_{1g}^{(c)\prime}$; whilst χ_{1H} and χ_{1C} are the hydrogen and carbon amplitudes in the benzene vibration $A_{1g}^{(c)}$, and χ_{2H} and χ_{2C} are the corresponding quantities for the benzene vibration $A_{1g}^{(n)}$. For the vibration $A_{1g}^{(n)\prime}$ we have similarly :

$$A_{1g}^{(n)\prime} = \xi_2 A_{1g}^{(n)} + \eta_2 A_{1g}^{(c)}$$

which means

$$\left.\begin{aligned} \chi'_{2H} &= \xi_2\chi_{1H} + \eta_2\chi_{2H} \\ \chi'_{2C} &= \xi_2\chi_{1C} + \eta_2\chi_{2C} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

The coefficients ξ and η are pure numbers which can be evaluated readily by inserting in equations (12) and (13) the amplitudes obtained from the equation of motion.

The components of the tensor $\Delta\alpha$ for a given frequency are proportional to the amplitudes of the vibration. The transformation of these components from benzene to hexadeuterobenzene is therefore given by the transformation coefficients ξ and η of the amplitudes. The relation of Raman intensity to the components of $\Delta\alpha$ is furnished by the well-known equation

$$I = \text{const.}\,(5A^2 + 13\gamma^2)I_{ex} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

in which I is the intensity of the Raman scattering observed at right angles to the monochromatic, non-polarised incident beam of intensity I_{ex}, and

$$A = d_{xx} + d_{yy} + d_{zz}$$
$$\gamma^2 = \tfrac{1}{2}[(d_{xx} - d_{yy})^2 + (d_{yy} - d_{zz})^2 + (d_{zz} - d_{xx})^2]$$

The d's are the three principal components of the tensor $\Delta\alpha$. Owing to the symmetry of the A_{1g} vibrations, A and γ are linear functions of the amplitudes χ, and therefore they will transform in the same way as the amplitudes themselves :*

$$\left.\begin{aligned} A_1' &= \xi_1 A_1 + \eta_1 A_2\,; \quad A_2' = \xi_2 A_1 + \eta_2 A_2 \\ \gamma_1' &= \xi_1\gamma_1 + \eta_1\gamma_2\,; \quad \gamma_2' = \xi_2\gamma_1 + \eta_2\gamma_2 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad (15)$$

The subscripts 1 and 2 refer, as before, to vibrations $A_{1g}^{(c)}$ and $A_{1g}^{(n)}$ respectively.

The calculation of intensities in hexadeuterobenzene is thus reduced to the problem of determining the A's and γ's for benzene. These are obtained with the help of the familiar depolarisation formula

$$\rho = 6\gamma^2/(5A^2 + 7\gamma^2) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (16)$$

By combining equations (14) and (16) with experimental data for ρ and I, A and γ may be evaluated on a relative intensity scale. Since we are interested only in relative intensities, absolute values of A and γ are not essential. It is possible to determine A and γ absolutely,

* $\Delta\alpha$ may be decomposed into a spherical and an anisotropic part, $\Delta\alpha_{sp.}$ and $\Delta\alpha_{an.}$. For $\Delta\alpha_{sp.}$ we have : $A \neq 0$, $\gamma = 0$; for $\Delta\alpha_{an.}$: $A = 0$, $\gamma \neq 0$. Owing to symmetry, $\Delta\alpha_{an.}$ (and of course also $\Delta\alpha_{sp.}$) can differ only by a numerical factor for different vibrations of the A_{1g} type. From this and the definition of A and γ, it follows that A and γ are linear functions of the amplitudes.

however, from the experimental ratio $(5A^2 + 13\gamma^2)/5A_0^2$ which is given in Carrelli and Went's table (*loc. cit.*); $A_0/3$, the polarisability of the non-vibrating molecule, may be calculated directly from the index of refraction (cf. Carrelli and Went, *loc. cit.*, p. 245; Stuart, "Molekülstruktur," Chap. 7).

When only two vibrations occupy a symmetry class, the most general expression for the potential energy of the vibrations contains three constants. In our case these three constants correspond to the interaction between hydrogen atoms, between carbon atoms, and between carbon and hydrogen atoms. Among the four observed A_{1g} frequencies (two in benzene and two in hexadeuterobenzene), there exists one relation, namely, the product rule (Part VIII, *loc. cit.*). We have used the three remaining independent values to determine from the equation of motion the three force constants, and from these the amplitudes of motion. The amplitudes substituted in equations (12) and (13) yield the ξ and η values, from which in turn the several A''s and γ''s have been determined. The following table lists the calculated values of A and γ in absolute units (c.c.). The amplitudes of vibration correspond to vibrational quantum number 3/2.

		Amplitudes, in 10^{-10} cm.		Transformation coefficients.		Change of polarisability, in 10^{-26} c.c.		Intensity.		Depolarisation ρ.	
Frequency.		C.	H.	ξ.	η.	A.	γ.	Obs.	Calc.	Obs.	Calc.
C_6H_6	$A_{1g}^{(c)}$	3·56	4·03	—	—	6·01	1·74	10·0	—	0·09	—
	$A_{1g}^{(h)}$	−0·66	7·01	—	—	−4·22	−3·33	10·6	—	0·4	—
C_6D_6	$A_{1g}^{(c)\prime}$	3·42	4·31	0·9696	0·0576	5·56	1·50	9·8	8·4	0·08	0·08
	$A_{1g}^{(h)\prime}$	−1·14	5·35	−0·1607	0·8565	−4·58	−3·14	10·4	10·5	0·35	0·34

The calculation of A and γ from equations (14) and (16) leaves the signs of both quantities indeterminate, since only their squares appear in the equations. A knowledge of the signs is essential if A' and γ' are to be determined from equation (15), and therefore the signs of the corresponding amplitudes must be considered. The signs in the table were so chosen for benzene that the calculated values of A' and γ' lead to agreement with the observed hexadeuterobenzene intensities. This agreement would not be affected if all the values of A or of γ or of both were to be multiplied by -1.

It is noteworthy that, although the amplitude ratio x_{1C}/x_{2C} in benzene is about -5, the experimental ratio of A_1 to A_2 is only $-1·5$, and γ_1/γ_2, $-0·5$. The fact that A and γ are relatively large in $A_{1g}^{(h)}$, despite the much smaller amplitude of the carbon atoms, indicates that the influence of the hydrogen atoms on $\Delta\alpha$ is considerable. The small amplitude of the carbon atoms in $A_{1g}^{(h)}$ is offset by the fact that the hydrogen atoms augment rather than counteract the portion of $\Delta\alpha$ due to the carbon ring, and there results the considerable intensity observed for $A_{1g}^{(h)}$. On the other hand, when the hydrogen atoms move in phase with the carbons (in $A_{1g}^{(c)}$) they tend to counterbalance the contribution of the latter to $\Delta\alpha$.

The effect produced on the polarisability of the expanding carbon ring by concomitant alteration of the carbon–hydrogen distance is rather contrary to the expected one, namely, that an increase in polarisability should result when a bond is stretched. This unusual behaviour may be due to the peculiar electronic structure of the carbon hexagon.* In the E_g^- vibration, the motion of the hydrogen ring affects $\Delta\alpha$ in more orthodox fashion. As we should anticipate, the contrary motion of the two ellipsoids in E_g^- results in the subtraction of the one contribution to $\Delta\alpha$ from the other.

4. *Intensities in the Class* E_g^+.—In principle, the difficulty of calculating intensity shifts by means of transformation coefficients is no greater for the four E_g^+ frequencies than for the two totally symmetrical frequencies. In practice, however, a quantitative calculation is out of the question, because a perfectly general potential system introduces into the secular determinant for E_g^+ more constants than one can evaluate from the observed E_g^+ frequencies. Intensity changes can be predicted qualitatively, however, from the behaviour of the polarisability during the A_{1g} vibrations. We may expect from analogy with the A_{1g} vibrations

* This singular electronic structure manifests itself also in the influence which the first chemical substituent in the benzene ring has on subsequent substitution (see Hückel, *Z. Physik*, **1931**, **72**, 310; Pauling and Wheland, *J. Chem. Physics*, **1933**, **1**, 362, 606).

that the two carbon frequencies of E_g^+ symmetry will have smaller carbon amplitudes and somewhat greater in-phase hydrogen amplitudes in hexadeuterobenzene. We have found that each of these changes leads to lower intensity, and therefore predict decrease in intensity for the two carbon frequencies. Experimentally, both are about 40% less intense in hexadeuterobenzene. It should be remarked in this connection that the intensity of the E_g^+ carbon frequency at 1596 cm.$^{-1}$ must be taken as the sum of the intensities of the two components of the resonance doublet, inasmuch as this sum must be equal to the sum of the intensity of the unperturbed fundamental frequency and the negligibly small intensity of the combination tone responsible for the perturbation.

In the E_g^+ hydrogen frequencies in hexadeuterobenzene, the effect of the larger carbon amplitudes on $\Delta\alpha$ will be offset by decrease in the out-of-phase hydrogen amplitudes. Which effect will predominate we cannot say without quantitative calculation. In $A_{1g}^{(\kappa)}$ the two were about equal, and the same is apparently true of the lower of the two E_g^+ hydrogen frequencies, for an intensity increase of less than 5% is observed. The effect of increased carbon amplitudes seems to be greater in the higher frequency, however, since this line is one-fourth more intense in hexadeuterobenzene.

The irregularity of the intensity changes produced by deuterium substitution is thus quite understandable. Qualitatively, and quantitatively where calculation is possible, the intensity shifts are just what we should expect from the intensity relationships in the Raman spectrum of benzene itself.

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365. *Chalkones. The Condensation of Aromatic Aldehydes with Resacetophenone.*

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Previous statements that resacetophenone does not react with benzaldehyde and protocatechualdehyde in presence of alkali to yield the corresponding chalkones, 2 : 4-dihydroxyphenyl styryl ketone and butein respectively, are incorrect. The use of dilute alkali solution provides a convenient method for transforming these chalkones into the corresponding hydroxyflavanones.

Ellison (J., 1927, 1720) gives m. p. 133—134° for 2 : 4-dihydroxyphenyl styryl ketone, obtained together with the isomeric 7-hydroxyflavanone (m. p. 189°) from resacetophenone and benzaldehyde in aqueous methyl-alcoholic solution, and reports that he was unable to prepare it from cinnamic acid and resorcinol in presence of zinc chloride by the method of Bargellini and Marantonio (*Atti R. Accad. Lincei*, 1908, **17**, 119), who record m. p. 175°. Shinoda and Sato (*J. Pharm. Soc. Japan*, 1928, **48**, 109) state that the preparation of polyhydroxychalkones from hydroxyacetophenones and aldehydes is beset with difficulty, and prefer to condense polyhydroxyphenols with cinnamoyl chlorides under the influence of aluminium chloride: 2 : 4-dihydroxyphenyl styryl ketone thus prepared had m. p. 151°. Mahal, Rai, and Venkataraman (J., 1935, 866) remark that resacetophenone does not react with benzaldehyde in presence of alkali to yield the chalkone; they obtained it (m. p. 151°) by debenzylation of 2-hydroxy-4-benzyloxyphenyl styryl ketone.

In view of these discrepancies we have re-examined the condensation of benzaldehyde with resacetophenone. Under Ellison's conditions 7-hydroxyflavanone (m. p. 189°) can be prepared in poor yield; 2 : 4-dihydroxyphenyl styryl ketone (m. p. 150°) can be obtained from resacetophenone and benzaldehyde by using excess of alkali at room temperature. Treatment of the chalkone with dilute sodium hydroxide solution (cf. Löwenbein, *Ber.*, 1924, **57**, 1515) then gives the flavanone in satisfactory yield.

Mahal, Rai, and Venkataraman (*loc. cit.*) obtained 7-benzyloxyflavanone (m. p. 102—104°) from 2-hydroxy-4-benzyloxyphenyl styryl ketone by treatment with phos-

phoric oxide in alcohol; we find, however, that a product, m. p. 126°, is obtained from the chalkone when dilute sodium hydroxide solution is used (Löwenbein, *loc. cit.*). Benzylation of 7-hydroxyflavanone gives the same product (m. p. 125—126°), which regenerates 7-hydroxyflavanone on debenzylation.

Shinoda, Sato, and Kawagoe (*J. Pharm. Soc. Japan*, 1929, **49**, 123) state that they were unable to repeat Göschke and Tambor's synthesis (*Ber.*, 1911, **44**, 3503) of butein by condensing protocatechualdehyde with resacetophenone in alcoholic alkali. We have, however, obtained the tetrahydroxychalkone from these components in alcoholic alkali by a suitable choice of conditions. Butin can be conveniently obtained from butein by treatment with dilute sodium hydroxide solution.

It is hoped to examine the possibility of the synthesis from hydroxyacetophenones and aldehydes of other hydroxy-chalkones and -flavanones.

Experimental.

2 : 4-*Dihydroxyphenyl Styryl Ketone from Benzaldehyde and Resacetophenone.*—A mixture of resacetophenone (5 g.), benzaldehyde (3·5 g.), alcohol (20 c.c.), and potassium hydroxide solution (75 g. in 100 c.c. of water) which had been kept for 12 hours at room temperature, diluted with water, and extracted with ether to remove unchanged benzaldehyde, gave on acidification with dilute hydrochloric acid an oil, which solidified in the refrigerator after 4 days. The dried solid (2·8 g.) crystallised from dilute alcohol and toluene (charcoal) in yellow needles, m. p. 150°, which gave a dark reddish-brown colour with alcoholic ferric chloride (Found: C, 75·0; H, 5·1. Calc. for $C_{15}H_{12}O_3$: C, 75·0; H, 5·0%).

7-*Hydroxyflavanone.*—(a) *From resacetophenone and benzaldehyde.* By Ellison's method (*loc. cit.*) the flavanone was obtained in poor yield as colourless needles, m. p. 189—190°, which gave no coloration with alcoholic ferric chloride (Found: C, 75·2; H, 5·1. Calc. for $C_{15}H_{12}O_3$: C, 75·0; H, 5·0%).

(b) *From* 2 : 4-*dihydroxyphenyl styryl ketone.* A mixture of the chalkone (1 g.) in alcohol (5 c.c.) and aqueous sodium hydroxide (15 c.c. of 1·5%) was heated under reflux for ½ hour, kept for 12 hours, diluted with water, and acidified with dilute acetic acid. The resulting precipitate separated from toluene (charcoal) in white needles (0·6 g.) giving no colour with alcoholic ferric chloride: m. p. and mixed m. p. with the product from (a) 189—190°.

(c) *From 2-hydroxy-4-benzyloxyphenyl styryl ketone.* The precipitate obtained on acidifying a mixture of the 4-benzyloxychalkone (Mahal, Rai, and Venkataraman, *loc. cit.*) (4 g.), alcohol (50 c.c.), and aqueous sodium hydroxide (60 c.c. of 1·5%) which had been heated under reflux for ½ hour and kept for 12 hours, gave on repeated crystallisation from alcohol (charcoal) 7-benzyloxyflavanone (2 g.), m. p. 126° (Found: C, 79·7; H, 5·5. Calc. for $C_{22}H_{18}O_3$: C, 79·8; H, 5·4%). A mixture of this (0·2 g.), glacial acetic acid (10 c.c.), and concentrated hydrochloric acid (15 c.c.) was heated under reflux for 30 minutes and diluted with water. The resulting precipitate separated from alcohol in white needles giving no colour with alcoholic ferric chloride and having m. p. and mixed m. p. with the product obtained from (a) 188—189°; the acetyl derivative had m. p. 98° (Ellison, *loc. cit.*, gives m. p. 98°).

Benzylation of 7-Hydroxyflavanone.—A mixture of 7-hydroxyflavanone (0·6 g.), benzyl chloride (3 g.), fused potassium carbonate (2 g.), and dry acetone (5 c.c.) was heated under reflux for 12 hours, the solvent evaporated, and the residue steam-distilled to remove the excess of benzyl chloride. The residual oil solidified overnight and crystallised first from alcohol and then from ether in white plates (0·15 g.), m. p. 124—125°, and 126° when mixed with the product from (c).

Condensation of Protocatechualdehyde with Resacetophenone: Preparation of Butein.—Potassium hydroxide solution (50 g. in 35 c.c. of water) was slowly added to a solution of protocatechualdehyde (5 g.) and resacetophenone (5·5 g.) in alcohol (7 c.c.) and the red mixture was heated at 100° for 10 minutes and kept out of contact with air for 12 hours. It was then diluted with an equal volume of water and acidified, with cooling, with dilute hydrochloric acid. The resulting precipitate (1·8 g.), crystallised from alcohol, had m. p. 212—213° and gave a dark purple colour with ferric chloride; the acetyl derivative had m. p. 128—129° (lit.: 210°, 213—215°; 129—131°).

Preparation of Butin.—A mixture of 1·5% sodium hydroxide solution (10 c.c.) and butein (1 g.) in alcohol (3 c.c.) which had been heated under reflux for ½ hour and kept at room temperature for 12 hours was diluted with water and acidified with dilute acetic acid. The yellow precipitate (0·5 g.) which slowly separated crystallised from water containing

alcohol in needles and from water in plates. After removal of water of crystallisation by drying under reduced pressure at 130°, it had m. p. 224—226°. It gave no violet coloration with alcoholic ferric chloride; the acetyl derivative had m. p. 122—125° (*lit.*: 221°, 224—226°; 123—125°).

Our thanks are due to Dr. K. Venkataraman for his helpful interest in this work.

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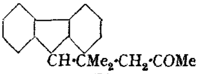
366. *The Condensation of Fluorene with Acetone. Part II.*

By HAROLD FRANCE, PETER MAITLAND, and S. HORWOOD TUCKER.

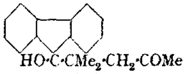
Fluorene reacts with acetone in the presence of potassium hydroxide. The acetone apparently condenses to form mesityl oxide, which, by a Michael reaction, combines with the fluorene, giving the compound (I). The action of certain reagents on (I) has given unexpected compounds, whose constitutions are being elucidated.

FLUORENE has been condensed with many aromatic aldehydes (Thiele, *Ber.*, 1900, **33**, 851; Thiele and Henle, *Annalen*, 1906, **347**, 290) by means of alcoholic sodium ethoxide or alcoholic alkali hydroxide, water being removed and the unsaturated compound formed. These authors (p. 291) state that fluorene does not react with aliphatic aldehydes or with alipnatic or aromatic ketones under these conditions. The same applies to 2 : 7-dibromofluorene (Sieglitz, *Ber.*, 1920, **53**, 1232). It was found, however (Maitland and Tucker, J., 1929, 2559), that when powdered potassium hydroxide was added to a solution of fluorene in acetone a vigorous reaction set in, and a white crystalline compound, $C_{19}H_{20}O$, m. p. 77—78°, was isolated (50% yield) together with a mixture of acetone condensation products —mesityl oxide, *iso*acetophorone, and higher-boiling materials having been characterised.

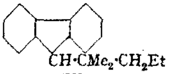
The compound, m. p. 77—78°, is *methyl* β-9-*fluorenyl*-β-*methyl*-n-*propyl ketone* (I), and is probably formed as a result of a Michael condensation of fluorenylpotassium and mesityl oxide (produced from acetone). This view has been confirmed by the synthesis of (I) by



(I.)



(II.)



(III.)

the condensation of (1) fluorene with mesityl oxide under comparable conditions (when pyridine was added, the yield was raised from 12 to 20%; it is still far below the 50% yield obtained with acetone), and (2) fluorenylsodium with mesityl oxide.

Methyl β-9-fluorenyl-β-methyl-*n*-propyl ketone (I) underwent the following reactions: (a) Dry distillation gave acetone, mesityl oxide, and fluorene—the simplest form of reversed Michael reaction (cf. Vorländer, *Ber.*, 1900, **33**, 3185; *Annalen*, 1906, **345**, 155; Ingold and Powell, J., 1921, **119**, 1976; Linstead, J., 1929, 2504). Similarly, by heating with concentrated alcoholic potassium hydroxide solution, fluorene was obtained.

(b) Heating with sodium in xylene (or potassium in benzene) gave rise to fluorene and *iso*propylidenefluorene, m. p. 110—113° (Maitland and Tucker, *loc. cit.*, p. 2563).

(c) The presence of the keto-group was proved by the formation of an oxime, a semi*carbazone*, and a 2 : 4-*dinitrophenylhydrazone*, but a phenylhydrazone could not be obtained. The colour reactions of ketones (Täufel and Thaler, *Z. physiol. Chem.*, 1932, **212**, 256) containing the group CH_2·CO·CH_2 was positive for acetone but negative for (I). The presence of CH_2·CO was indicated by the ready condensation with piperonal and with 6-bromopiperonal in alkaline alcoholic solution. Whether the compounds contain the group R·CH:C·CO·CH_3 or CH_3·CO·CH:CHR was not investigated, but the latter is more likely for steric reasons. The substance (I) in solution appears to contain no enolic modification, since it failed to react with acid chlorides or phenyl *iso*cyanate and gave no gas when treated with methylmagnesium iodide. Attempts to convert the terminal

$CO{\cdot}CH_3$ group into CO_2H failed (cf. Ramage and Simonsen, J., 1935, **1583**, for failure with a comparable side chain), but sodium hypobromite gave a smell of bromoform and sodium hypoiodite gave iodoform (test according to Fuson, *Chem. Rev.*, 1934, **15**, 275; Fuson and Tullock, *J. Amer. Chem. Soc.*, 1934, **56**, 1638; 1935, **57**, 919).

(d) Bromination gave *mono-*, *di-*, and *tri-bromo*-substitution products. Oxidation of these (sodium dichromate and glacial acetic acid) gave fluorenone, proving that substitution was entirely in the side chain. Since the tribromo-derivative might conceivably contain the group $CO{\cdot}CBr_3$, it was heated with aqueous potassium hydroxide to effect the change to CO_2H, but without avail.

(e) Oxidation with potassium permanganate in acetone solution gave a crystalline *compound*, $C_{19}H_{20}O_2$, m. p. 120—122°, which is possibly methyl β-9-hydroxy-9-fluorenyl-β-methyl-*n*-propyl ketone (II); it was not further investigated. Oxidation of (I) with sodium dichromate in glacial acetic acid solution gave fluorenone.

(f) Reduction by the Clemmensen or the Kischner-Wolff method gave β-9-*fluorenyl*-β-*methylpentane* (III), m. p. 84—85°, whose constitution was confirmed by two syntheses: (i) reaction between αα-dimethylbutylmagnesium chloride and fluorenone, with subsequent hydrolysis and reduction with hydriodic acid; (ii) reaction between αα-dimethylbutyl chloride and sodiofluoreneoxalic ester (or potassiofluorenecarboxylic ester), followed by hydrolysis.

(g) Hydriodic acid gave, instead of the expected compound $C_{19}H_{22}$ (III), a *substance*, $C_{19}H_{20}$, m. p. 103—104°, which was also obtained in small yield by the Clemmensen reduction of (I). It is a saturated compound, since it did not react with hydrogen in the presence of a palladium catalyst. Dry hydrogen bromide in glacial acetic acid reacted with (I) to give crystals which spontaneously, in air, lost hydrogen bromide, giving a *substance*, $C_{19}H_{18}$, m. p. 77—79°. This, on reduction, gave the substance $C_{19}H_{20}$.

(h) Heating with zinc chloride gave not only the saturated substance, $C_{19}H_{20}$, m. p. 103—104°, but also a yellow *substance*, $C_{16}H_{14}$(?), m. p. 131—133°. Phosphoric oxide acted similarly, but gave only the substance, m. p. 131—133°. This appears to be saturated, since it does not decolorise potassium permanganate solution.

Attempts to reduce the *oxime* of (I) failed. The Beckmann transformation of the oxime gave a *product*, $C_{19}H_{21}ON$, m. p. 167—169°, which, however, failed to give an isolable acid on hydrolysis.

2 : 7-Dibromofluorene could not be condensed with acetone, although Sieglitz (*loc. cit.*) has shown that with aromatic aldehydes 2 : 7-dibromofluorene reacts more readily than fluorene. Fluorene and methyl ethyl ketone also failed to give a condensation product.

The condensation of indene and acetone is being investigated.

Experimental.

Methyl β-9-*Fluorenyl*-β-*methyl*-n-*propyl Ketone* (I).—(a) *Condensation of fluorene and acetone*. Fluorene (20 g.) was dissolved in warm acetone (120 c.c.) in a large beaker, the solution allowed to cool somewhat—but without separation of fluorene—and fused (stick), finely powdered potassium hydroxide (80 g.; or 160 g. of laboratory powder, which invariably contains moisture) stirred in rapidly. The solution became deep blue-green, the acetone boiled vigorously, and, almost immediately after the violence of the reaction had subsided, the mixture thickened. An equal volume of cold water was *at once* added. The green oil which separated was removed and washed several times with 50% sulphuric acid (to remove acetone, mesityl oxide, and other acetone condensation products), the thick orange oil thus obtained was extracted with ether, and the extract washed with aqueous sodium carbonate, then with water, dried (sodium sulphate), and evaporated. The oily solid obtained crystallised from acetic acid or alcohol in colourless needles, m. p. 77—78° (15·5 g.; 50% yield) (Found: C, 86·4; H, 7·65; *M*, cryoscopic in benzene, 259. $C_{19}H_{20}O$ requires C, 86·4; H, 7·6%; *M*, 264).

When, in early experiments, the sulphuric acid used as above was dilute, the condensation products were not removed and (I) could not be isolated from the oil. If, however, the oil was steam-distilled, (I) (which distils very slowly) was left behind in a form which could be easily crystallised. The acetone condensation products distilled: of these, mesityl oxide, phorone, and *iso*phorone (giving two oximes, m. p.'s 74—75° and 99—100°; Bredt, *Annalen*, 1898, **299**, 170; Kerp and Müller, *ibid.*, p. 219) were identified.

(b) *Condensation of fluorene and mesityl oxide.* Fluorene (10 g.) was dissolved in warm mesityl oxide (30 c.c.) (prepared by distilling diacetone alcohol with a crystal of iodine), pyridine (2 or 3 drops) added, then potassium hydroxide (fused, powdered; 30 g.) with vigorous stirring. The mixture darkened at once and the reaction became violent, but judicious cooling prevented charring (which is inevitable if the reaction gets out of control). When the mixture became semi-solid, it was worked up as above. The product (15—20% yield) melted at 77—78° alone or mixed with that obtained by process (a). When pyridine was omitted, the reaction was more violent and the yield reduced to 12%. When piperidine (a few drops) replaced pyridine, only a trace of (I) was obtained.

The possibility that in the condensation of mesityl oxide with fluorene the former is decomposing into acetone, which then condenses with the latter, as shown under (a), is rendered unlikely by the observation that mesityl oxide (10 c.c.), treated with potassium hydroxide under the above conditions of experiment (but omitting fluorene), gave only a trace of acetone (3—5 drops). The possibility that continuous removal (by fluorene) of acetone as soon as it is formed might enable the reaction to go to completion cannot apply in method (c).

No condensation of fluorene and mesityl oxide (in absence of potassium hydroxide) could be effected by molar quantities of piperidine, sodium ethoxide or sodamide (for lack of reactivity of mesityl oxide in analogous cases, see Rapson, J., 1936, 1626).

(c) *Condensation of fluorenylsodium and mesityl oxide.* Fluorenylsodium was prepared thus: Fluorenone ⟶ fluorenol ⟶ 9-bromofluorene ⟶ 9-methoxyfluorene ⟶ fluorenylsodium.

Fluorenol. Magnesium turnings (35 g.; excess) were added, with cooling, to a solution of fluorenone (70 g.) in methyl alcohol (1 l.) at 45°. The mixture was heated for 2 hours, an excess of acetic acid added to dissolve unchanged magnesium and magnesium methoxide, methyl alcohol removed by distillation, and the residue treated with excess of water. The white precipitate obtained crystallised from benzene or alcohol in colourless needles, m. p. 154—156° (containing benzene of crystallisation, removed at 100°).

9-*Methoxyfluorene.* Kliegl (*Ber.*, 1929, **62**, 1327) gives a method of preparation from 9-chlorofluorene. 9-Bromofluorene (5 g.) and silver nitrate (3·4 g., finely powdered) were refluxed in methyl alcohol (100 c.c.) for ½ hour. The filtered solution was poured into water; the oil which separated solidified in ice and crystallised from ligroin in white needles, m. p. 42—43° (3·4 g.; 85% yield).

Fluorenylsodium. This was prepared by the Schlenk technique (Houben-Weyl, 1924, Vol. IV, pp. 957—965), 9-methoxyfluorene being acted upon with atomised sodium in dry ether (distilled from phosphoric oxide) and an atmosphere of pure dry nitrogen (cf. benzhydrylsodium; Bergmann, J., 1936, 412). After 48 hours' shaking, the solution became dark red-brown. It was filtered, from one Schlenk tube to another, through an intermediate straight " calcium chloride tube " packed with ignited asbestos, this being found preferable to a sinter disc tube.

Mesityl oxide (0·75 g.) was added to a solution of fluorenylsodium (from 1·5 g. of 9-methoxyfluorene) in ether contained in a Schlenk tube (nitrogen atmosphere), which was then sealed. After 48 hours, the solution was treated with water and the ethereal solution was separated, washed with dilute acid and with water, and dried. Evaporation gave an orange oil, which on crystallisation from alcohol gave fluorene (0·8 g.), then colourless needles of (I), m. p. 77—78° (0·5 g.; 55% yield, calc. on unrecovered fluorene). Its identity was confirmed by the mixed m. p. method.

9-Benzoylfluorene (m. p. 136—138°; Werner, *Ber.*, 1906, **39**, 1287) was similarly obtained by the action of fluorenylsodium on benzyl benzoate.

Attempts were made to condense 9-fluorenyldimethylcarbinyl chloride (Courtot, *Ann. Chim.*, 1915, **4**, 162. The yield is improved by keeping the alcoholic solution of the carbinol cold during the passage of hydrochloric acid) and also the corresponding bromide (Maitland and Tucker, *loc. cit.*, p. 2563) with sodioacetoacetic ester, but without avail.

Dry Distillation of (I).—Gentle heating of (I) (50 g.) during 4 hours gave a distillate, which was fractionated into acetone (4 c.c.) and mesityl oxide (6 c.c.), the latter being identified by its semicarbazone (m. p. 156°). The solid residue was fluorene.

Fluorene (m. p. 115°; 2—2·5 g.) was likewise obtained by boiling (I) (10 g.) with potassium hydroxide (20 g.) in alcohol (20 c.c.) for 5 minutes and acidifying and steam-distilling the product. (I) remained unchanged after boiling with sulphuric acid solutions (10—50%).

Action of Sodium on (I).—The substance (1 g.) was heated with atomised sodium in xylene (4 c.c.) for 4 hours. A good yield of fluorene was obtained.

Action of Potassium on (I).—The substance (2 g.) was heated with atomised potassium (0·4 g.)

in benzene (50 c.c.) for 8 hours. The mixture turned red. After filtration and removal of benzene by distillation, the residue was crystallised from excess of alcohol and gave, first, long orange-yellow needles of 9-*iso*propylidenefluorene (m. p. 113—117°) and then, on evaporation, fluorene.

9-*iso*Propylidenefluorene, on keeping, turns to an oil, which after successive crystallisation from alcohol and ligroin, gives yellow plates of fluorenone, m. p. 80—82°.

Piperonylidene Derivative of (I).—The substance (4 g.) and piperonal (2·5 g.) were dissolved in alcohol (25 c.c.), 20% sodium hydroxide solution (0·3 c.c.) added, and the mixture boiled (½—1 hour) and concentrated. The crystals obtained on cooling were recrystallised from alcohol or alcohol–glacial acetic acid until very faintly green cubes were obtained, m. p. 167—168° (Found : C, 81·7; H, 6·1. $C_{27}H_{24}O_3$ requires C, 81·8; H, 6·1%).

The 6-*bromopiperonylidene* derivative was similarly prepared (Found : Br, 16·9. $C_{27}H_{23}O_3Br$ requires Br, 16·8%).

Oxidation of (I).—(a) *With potassium permanganate in acetone.* The substance (20 g.) was dissolved in acetone (200 c.c., purified by boiling with potassium permanganate, drying, and distillation), and potassium permanganate (40 g.) added during 10 hours. After filtration, and addition to the filtrate of an acetone extract of the residue, evaporation gave an oil. Crystallisation of this from alcohol gave, first, unchanged material, then crops of mixed prisms and needles. Warming with alcohol removed the needles. The prisms on recrystallisation gave the *compound* (II) (1 g.), m. p. 120—122°. It was neutral to litmus (Found : C, 81·1; H, 7·2. $C_{19}H_{20}O_2$ requires C, 81·4; H, 7·1%).

(b) *With sodium dichromate in glacial acetic acid.* The substance (I) (5 g.) was boiled with sodium dichromate (40 g.) in glacial acetic acid (200 c.c.) for 5 hours, and the product poured into water. A chloroform extract, on steam distillation, gave fluorenone.

(c) Hypobromite and hypoiodite acted on (I) to give bromoform and iodoform respectively, but no other products could be isolated.

Reduction of (I).—(i) *Kischner–Wolff method.* Schönberg's modification (*Ber.*, 1921, **54**, 2838) of the method was used. The *semicarbazone* of (I) (colourless rods, m. p. 218°, from alcohol. Found : C, 74·7; H, 7·1; N, 13·1. $C_{20}H_{23}ON_3$ requires C, 74·8; H, 7·2; N, 13·1%) (5 g.) was heated with sodium ethoxide (1·5 g. of sodium in 20 c.c. of ethyl alcohol) in a sealed tube at 200° for 12 hours : a high pressure developed and an inflammable gas was formed. The partly crystalline product was treated with an excess of dilute hydrochloric acid, and the precipitated solid crystallised from alcohol. It was β-9-*fluorenyl*-β-*methylpentane* (III) (1·9 g.), m. p. 84—85° (Found : C, 91·0; H, 8·8; *M*, 221. $C_{19}H_{22}$ requires C, 91·2; H, 8·8%; *M*, 250).

(ii) *Clemmensen method.* The substance (I) (10 g.) and amalgamated zinc (150 g.) were heated for 12 hours with concentrated hydrochloric acid (addition of anisole was without advantage; cf. Robinson and Ramage, J., 1933, 608), hydrogen chloride being passed in from time to time and more zinc added after the first 6 hours. After cooling, the whole was extracted with ether. The extract, washed with sodium carbonate solution, gave a yellow oil, which was dissolved in hot alcohol (charcoal); on slow cooling, a greenish-yellow oil separated, followed by tufts of white needles. These, together with a small amount of oil, were recrystallised from alcohol, giving white needles, m. p. 84—85°, of β-9-fluorenyl-β-methylpentane (III). Further crops of crystals, on recrystallisation from methyl alcohol or acetone, gave colourless needles of a *substance*, m. p. 103—104° (Found : C, 91·9; H, 8·1; *M*, 246. $C_{19}H_{20}$ requires C, 91·9; H, 8·1%; *M*, 248).

(iii) *By hydriodic acid.* A solution of the substance (I) (2 g.) in glacial acetic acid (70 c.c.) and hydriodic acid (*d* 1·7; 4 c.c.) was boiled under reflux for 2—3 hours. It was then poured into excess of sulphurous acid, the solution extracted with ether, and the extract made alkaline with concentrated sodium carbonate solution, washed with water, and dried (sodium sulphate). Evaporation left an oily solid, which crystallised from methyl alcohol in long white needles (0·4—0·5 g.), m. p. 103—104°, identical with the substance $C_{19}H_{20}$ described under (ii).

Attempts to reduce (I) by sodium in alcohol or by means of *iso*propylmagnesium bromide or *cyclo*hexylmagnesium bromide (Gilman and Zoellner, *J. Amer. Chem. Soc.*, 1931, **53**, 1945) were unsuccessful.

Syntheses of β-9-*Fluorenyl*-β-*methylpentane* (III).—(i) *From fluorenone and αα-dimethylbutyl chloride.* Dimethylpropylcarbinol (Deschamps, *J. Amer. Chem. Soc.*, 1920, **42**, 2670—the compound he describes as the phenylurethane of dimethylpropylcarbinol is, we find, diphenylurea; cf. Fessler and Shriner, *ibid.*, 1936, **58**, 1384) was obtained in the usual way from acetone (145 c.c., purified by distillation of its sodium iodide compound) and the Grignard reagent prepared from *n*-propyl bromide (181 c.c.), magnesium (48 g.), and ether (500 c.c.). The yield of carbinol,

b. p. 121—125°, was 139 g. (62%). The carbinol (40 g.) was converted into αα-dimethylbutyl chloride (Schreiner, *J. pr. Chem.*, 1910, **82**, 292) by addition of concentrated hydrochloric acid (130 c.c.); in a few seconds the clear liquid became turbid and separated into two layers. The mixture, after boiling for ½ hour, was left for a day and the upper layer was removed, washed with water, shaken with concentrated sulphuric acid, kept until all acid had separated, and distilled. The chloride (40 g.), b. p. 111—113°, was thus obtained without fume. The washing with sulphuric acid removes carbinol, which otherwise causes fuming by reaction with the chloride.

A Grignard solution was prepared from the above chloride (10 c.c.), magnesium (1·5 g.), ether (15 c.c.), and a crystal of iodine. It was decanted from unchanged magnesium, and finely powdered fluorenone (6 g.) sifted in during 1 hour (ice). Next day, more ether (20 c.c.) was added, and the mixture boiled for 2 hours and worked up in the usual way. The oil obtained, on distillation in a vacuum, gave fluorenone and then an oil (1 g., b. p. 210—240°/25 mm.) which could not be crystallised. It was boiled with hydriodic acid (4 c.c.), red phosphorus (2 g.), and glacial acetic acid (40 c.c.) for 2 hours. After filtration and treatment with sulphurous acid, a sticky solid separated, which crystallised from alcohol and proved to be (III), m. p. 84—85°.

(ii) *From sodiofluoreneoxalic ester and αα-dimethylbutyl chloride.* Sodium (1·2 g.) was dissolved in ethyl alcohol (25 c.c.) on the water-bath, and fluorene (8·4 g.) added, followed by ethyl oxalate (7·4 g.), which converted the white pasty mass into an orange solution of sodiofluoreneoxalic ester. This was heated on the boiling water-bath (½ hour), and αα-dimethylbutyl chloride (10 g., excess) added; after 2—3 hours at 100° there was a considerable precipitate of sodium chloride, due to decomposition of the tertiary chloride, confirmed by the typical olefinic smell. The mixture was treated with water, and the oil which separated boiled with 20% sodium hydroxide solution for 1—2 hours. The mixture was extracted with ether, the inorganic matter removed and extracted with ether, and the combined extracts clarified (charcoal), dried (sodium sulphate), and allowed to evaporate in stages; the first crops of crystals were fluorene; later crops on recrystallisation from alcohol gave (III), m. p. 84—85° (0·3—0·4 g.; 5% yield). The identity of these synthetic products with that obtained by the Kischner-Wolff method was confirmed by the method of mixed m. p.'s.

(III) was synthesised similarly from potassiofluorenecarboxylic ester and αα-dimethylbutyl chloride, but in very poor yield.

9-*Fluorenyldimethylcarbinyl iodide*, prepared by mixing 9-fluorenyldimethylcarbinol with a cold solution of hydriodic acid (*d* 1·7), separated in yellow needles after several hours and crystallised from ligroin (b. p. 70—80°) in colourless rods, m. p. 95—97° with evolution of iodine (Found: I, 38·1. $C_{16}H_{15}I$ requires I, 38·0%). It decomposed on standing, giving iodine.

Synthesis of tert.-*Butylfluorene*.—The method was essentially that described under (ii), sodiofluoreneoxalic ester and *tert*.-butyl iodide (15 g.) or *tert*.-butyl chloride (10 g.) being used. No decomposition of the tertiary compounds was observed and white needles (2%), m. p. 101—102°, were obtained from acetic acid or methyl alcohol. *tert*.-Butylfluorene could not be obtained when sodiofluorenecarboxylic ester was used.

Action of Hydrogen Bromide on (I).—Hydrogen bromide was passed into a solution of (I) (5 g.) in glacial acetic acid (50 c.c.) for 4 hours; crystals began to separate after about ½ hour (when removed, these lost hydrogen bromide spontaneously, but their m. p. taken at once was 95—105°). Next day, the solid was collected and heated at 100° in a stream of air until hydrogen bromide was no longer evolved (1 hour). The brown solid left was dissolved in alcohol (charcoal), and finally obtained from methyl alcohol in white rods of a *substance* (2·9 g.), m. p. 77—79° (Found: C, 92·7; H, 7·3; *M*, 256. $C_{19}H_{18}$ requires C, 92·7; H, 7·3%; *M*, 246).

Oxidation of the Substance $C_{19}H_{18}$, *m. p.* 77—79°.—A solution of the substance (1 g.) in acetone (20 c.c., purified by boiling with potassium permanganate) containing a trace of water and potassium permanganate (3 g.) was boiled for 3—4 hours, poured into water, made alkaline with sodium hydroxide, filtered, extracted with ether, acidified with sulphuric acid, and extracted with ether. Evaporation left a yellow oil, which crystallised from acetic acid, on dilution with water, in short colourless prisms of a *substance*, m. p. 163—164° (20% yield) (Found: C, 77·4; H, 6·2. $C_{19}H_{18}O_3$ requires C, 77·5; H, 6·1%). This substance was an acid. It gave the iodoform reaction, and a precipitate with 2 : 4-dinitrophenylhydrazine.

Catalytic Hydrogenation of $C_{19}H_{18}$ *to* $C_{19}H_{20}$.—The substance $C_{19}H_{18}$ (4 g.) was dissolved in warm glacial acetic acid (100—150 c.c.) and treated with hydrogen in presence of a palladium catalyst prepared from palladous chloride (0·2 g.); occasional warming was necessary to maintain solution. The volume of hydrogen absorbed was somewhat in excess of that required

for the reduction of the double bond, but the yield of the hydrocarbon $C_{19}H_{20}$, m. p. 103—104°, was 95% of the theoretical.

Action of Zinc Chloride on (I).—The substance (I) (5 g.) was heated with anhydrous zinc chloride (10 g.) at 240—250° for 2 hours. The product was cooled, dilute hydrochloric acid added, and the mixture extracted with ether. Evaporation of the ether left an oil, which was taken up in acetic acid; from this solution, a yellow oily solid separated. From an alcoholic solution (charcoal), which was colourless and blue-fluorescent, there separated yellow prisms of a *substance*, m. p. 133—134° (after vacuum sublimation and crystallisation from acetone) (Found: C, 93·1; H, 6·7; *M*, 214. $C_{16}H_{14}$ requires C, 93·2; H, 6·8%; *M*, 206). The alcoholic solution on concentration deposited the substance $C_{19}H_{20}$, m. p. (after recrystallisation from acetic acid) and mixed m. p. 102—104°.

Action of Phosphoric Oxide on (I).—Equal weights of the oxide and (I) were fused at 250° for 3 hours; the mixture, which finally became brown, was extracted with water. An ethereal extract of the residue had a green fluorescence and, after being washed with sodium carbonate solution, gave an oil which separated from glacial acetic acid (charcoal) in yellow crystals, m. p. 133—134° alone or mixed with the yellow product above.

Oxime of (I).—A solution of (I) (30 g.) in alcohol (300 c.c.) was boiled with hydroxylamine hydrochloride (28 g. in 80 c.c. of water) and potassium hydroxide (28 g. in 40 c.c. of water) for ¾ hour, poured into water, and left overnight. The *oxime* crystallised from alcohol in white needles (21 g.), m. p. 109—110° (Found: C, 81·9; H, 7·4; N, 5·0. $C_{19}H_{21}ON$ requires C, 81·7; H, 7·5; N, 5·0%). It dissolved in its own bulk of acetic anhydride with evolution of heat and after 2 days large thick plates of the *acetyl* derivative separated, m. p. 90—94° after recrystallisation from alcohol (Found: C, 78·8; H, 7·4; N, 4·4. $C_{21}H_{23}O_2N$ requires C, 78·5; H, 7·2; N, 4·4%).

Action of Phosphorus Pentachloride on the Oxime of (I).—The oxime (10 g.) in anhydrous ether (80 c.c.) was *rapidly* stirred at room temperature, and phosphorus pentachloride (10—12 g.) added during 10 minutes. After a further 45 minutes' stirring, most of the ether had evaporated. The residue, treated with iced water, gave a yellow paste, which was extracted with chloroform (60—70 c.c.). The pale yellow extract was washed with sodium carbonate solution and with water, dried, and evaporated. The yellow viscous residue was left in a vacuum, overnight; it separated from toluene or methyl alcohol in white crystals, m. p. 167—169° (Found: N, 5·25. $C_{19}H_{21}ON$ requires N, 5·0%). Hydrolysis of this *amide* gave uncrystallisable amines and no solid acid.

Bromination of (I).—*Monobromo-derivative.* The substance (I) (10 g.) was dissolved in carbon disulphide (100 c.c.), and bromine (7 g., slight excess) in carbon disulphide (70 c.c.) added during 1 minute; after 5 minutes, the solvent was removed by a current of air. The residue crystallised from ligroin (160 c.c.) in large stout rods (6 g.), m. p. 83—85° (Found: Br, 23·5. $C_{19}H_{19}OBr$ requires Br, 23·3%); the mother-liquor on concentration deposited the dibromo-compound.

Dibromo-derivative. Bromine (3·9 g.) in carbon disulphide (20 c.c.) was added gradually to a boiling solution of (I) (4 g.) in carbon disulphide (40 c.c.). After ½ hour's boiling, the solvent was evaporated in a current of air, and the oily residue dissolved in hot alcohol (56 c.c.). The semi-crystalline mass after recrystallisation melted at 102—104° (Found: Br, 34·2. $C_{19}H_{18}OBr_2,C_2H_5{\cdot}OH$ requires Br, 34·2%. Found for material crystallised from ligroin: Br, 38·1. $C_{19}H_{18}OBr_2$ requires Br, 37·9%).

Tribromo-derivative. The substance (I) (4 g.) was dissolved in carbon disulphide (40 c.c.), and bromine (10·5 g.) in carbon disulphide (60 c.c.) added while the temperature was gradually raised. After an hour's boiling, the bromine-coloured solvent was evaporated, and the sticky residue crystallised from alcohol, plates and then needles separating. After two recrystallisations the *tribromo*-derivative was obtained in stout white needles, m. p. 173—175° (Found: Br, 48·0. $C_{19}H_{17}OBr_3$ requires Br, 47·9%).

Attempts to prepare a mono- and a dibromo-derivative by the condensation of the corresponding bromo-derivative of fluorene with acetone by means of potassium hydroxide were unsuccessful.

Nitration of (I).—The substance (2 g.) was dissolved in glacial acetic acid (8 c.c.), and a mixture of concentrated nitric and sulphuric acids (4 : 1, 12 c.c.) added during 5 minutes, with cooling. After 1 minute the solution was poured into water, and the yellow sticky mass washed by decantation with water. It crystallised from alcohol in light yellow needles, m. p. 110—114° (Found: C, 74·1; H, 6·4; N, 4·6. $C_{19}H_{19}O_3N$ requires C, 73·8; H, 6·1; N, 4·5%). On one occasion there was obtained a *substance* crystallising from alcohol in yellow plates, m. p. 98—100° (1·7 g.) (Found: N, 5·3. $C_{16}H_{15}O_3N$ requires N, 5·2%).

***Reduction of the Nitro-compound of* (I), m. p. 110—114°.**—Reduction with zinc in glacial acetic acid gave a substance, crystallising in brownish prisms, m. p. about 220°, which was not an amine and was not identified. Reduction in alcoholic solution with tin and hydrochloric acid was ineffective.

The nitro-compound (12 g.) was dissolved in alcohol (600 c.c.), sodium sulphide (60 g.) in water (150 c.c.) added, and the solution boiled for 3 hours (water being added occasionally to prevent bumping) and poured into water. The yellow solid obtained was dried and dissolved in alcohol, an equal bulk of concentrated hydrochloric acid added together with a few pieces of tin, and the whole boiled for a new minutes. The clear solution was decanted into excess of concentrated potassium hydroxide solution. The precipitate obtained was redissolved in concentrated hydrochloric acid, and again poured into concentrated potassium hydroxide solution. The solid was washed, dried, and crystallised twice from alcohol (charcoal), forming cream-coloured needles (8 g.), m. p. 143—146° (Found : C, 81·7; H, 7·2; N, 5·2. $C_{19}H_{21}ON$ requires C, 81·7; H, 7·5; N, 5·0%).

We gratefully acknowledge financial assistance from the Chemical Society and from the Government Grants Committee of the Royal Society, also the grant of a Carnegie Scholarship to one (H. F.) of us. We are indebted to Miss M. C. Nelmes, B.Sc., who performed several of the Rast estimations of molecular weight, and to Mr. J. M. L. Cameron, who carried out the micro-analyses.

University of Glasgow. [*Received, September 4th*, 1937.]

NOTES.

Estimation of Deuterium Oxide–Water Mixtures. By William H. Patterson.

In many experiments with heavy water a rapid method of estimating the D_2O content by using only small quantities is desirable. With this in view, critical and mutual solubility methods were tested, correlated with direct determination of density.

A mixture of ethyl alcohol and ordinary paraffin (*n*-decane) has a *C.S.T.* a little above room temperature and is very sensitive to traces of water, 1 mg. of which raises the *C.S.T.* of a mixture of 0·5 g. of each of the organic liquids by 1·7°. The effect of D_2O, however, was nearly the same (slightly lower), no doubt owing to rapid exchange.

The following results relate only to the system D_2O–H_2O–phenol, for which constant results were found unchanged after several days. Timmermans and Poppe (*Compt. rend.*, 1935, **201**, 524) gave 12·25° as the rise of *C.S.T.* when D_2O replaces H_2O, and Hall, Wentzel, and Smith (*J. Amer. Chem. Soc.*, 1934, **56**, 1822) found a 5·58° rise on using water with 47·2% D_2O content ($N = 0·466$). The choice of the actual temperature of mutual miscibility is to some extent arbitrary. When concentrations near to the critical are tried (giving the *C.S.T.*), a range of opalescence of nearly 3° is found; 10% change of phenol content on either side reduces this to 0·5°. In all cases, however, the advent of turbidity or opaqueness is sharp and definite, and when this is used as standard the *C.S.T.* of water–phenol is 66·0° and no change can be noted with variations in phenol content between 34·2 and 37·8% (Carrington, Hickson, and Patterson, J., 1925, **127**, 2544).

A pyknometer was used for density determinations, made by blowing a bulb on a tube and drawing the ends into capillaries to give a **V**-shape. Since an ordinary balance was used for weighing, the pyknometer was made to have a volume of 0·4882 c.c., and measurements with it were found to be as accurate as allowed by possible errors in weighing (0·1—0·2 mg.). For similar reasons a few cg. were taken in the miscibility tests. Use of a micro-balance would probably increase accuracy even with smaller samples.

Mixtures were made by diluting the original sample, stated to be 99·6% D_2O, $d_{4^\circ}^{20^\circ}$ 1·10495 (Found : 1·1043, after the tube had been opened several times). Since the nature of the curves had first to be studied, no attempt was made to measure temperature differences below 0·05°. The following results were obtained :

(1) D_2O 99·6% ($N = 0·996$), $d_{4^\circ}^{20^\circ}$ 1·1043.

PhOH, % ...	50·1	45·2	38·5	36·3	33·9	26·3	24·9	24·1	23·1	22·0	19·6
M.M.T.	74·10°	76·35°	77·75°	78·00°	78·15°	77·95°	77·95°	77·75°	77·75°	77·3°	76·25°

Max. : 78·2°; phenol, 31%.

(2) D_2O 66·76% (N = 0·644), $d_{4°}^{20°}$ 1·0678.

PhOH, %	49·6	47·3	37·3	30·2	28·2	24·9
M.M.T.	70·30°	72·30°	74·25°	74·40°	74·2°	74·0°

Max.: 74·40°; phenol, 32·5%.

(3) D_2O 52·65% (N = 0·500), $d_{4°}^{20°}$ 1·0506.

PhOH, %	50·4	44·0	35·7	30·9	28·1	23·1	21·5	16·5
M.M.T.	67·30°	71·15°	72·35°	72·20°	71·90°	71·25°	70·70°	67·30°

Max.: 72·20°; phenol, 33%.

(4) D_2O 19·53% (N = 0·179), $d_{4°}^{20°}$ 1·0170.

PhOH, %	48·8	41·6	36·4	25·9	19·3
M.M.T.	66·2°	68·05°	68·55°	68·05°	65·5°

Max.: 68·6°; phenol, 35%.

The figures show that densities have a slight negative deviation from linear. The critical concentration of the phenol changes progressively from 36·1% with H_2O to 31·0% for D_2O. Otherwise the curves are similar and enable concentrations other than critical to be used for estimation.

The temperature rise in replacing H_2O by alleged 99·6% D_2O and by 52·65% D_2O is 12·2° and 6·2° respectively. The latter mixture is equimolar (N = 0·5), so a rise of 1·24° represents 0·1 mol. fraction of D_2O. This figure enables an approximate analysis to be made. For intermediate concentrations slight increase is necessary: the figure calculated from the results of Hall, Wentzel, and Smith (*loc. cit.*) is 1·25°.

This variation, which needs more accurate determination if results correct to 1% are required, is probably due to the fact that only three curves are concerned with two-component systems, *i.e.*, phenol and 100% D_2O, 52·65% D_2O (corresponding to HDO), or 100% H_2O: all other curves represent three-component systems.—QUEEN MARY COLLEGE, UNIVERSITY OF LONDON. [*Received, August 25th*, 1937.]

The Preparation of 2 : 4-Dinitrobenzonitrile and 2 : 4-Dinitrobenzoic Acid. By FREDERICK R. STORRIE.

THE Curtius–Bollenbach method of preparing 2 : 4-dinitrobenzoic acid (*J. pr. Chem.*, 1907, **76**, 287) by the chromic anhydride oxidation of 2 : 4-dinitrotoluene in sulphuric acid is not satisfactory (cf. Borsche and Butschli, *Annalen*, 1936, **522**, 285).

We have prepared 2 : 4-dinitrobenzonitrile by diazotising 2 : 4-dinitroaniline by Hodgson and Walker's method (J., 1933, 1620), using potassium nickelocyanide (Korczyński, Mroziński, and Villau, *Compt. rend.*, 1920, **171**, 183) instead of the cuprocyanide (which gives less than a 60% yield of a very impure nitrile), and having the reaction mixture neutral (cf. "Organic Syntheses," IV, 70). The hydrolysis of the nitrile to the amide, and the conversion of the latter into the acid by means of nitrous acid, can be accomplished without isolation of the amide.

A filtered solution of 2 : 4-dinitrobenzenediazonium sulphate (prepared by Hodgson and Walker's method from 18·3 g. of 2 : 4-dinitroaniline in 175 c.c. of glacial acetic acid, and 7·7 g. of sodium nitrite in 55 c.c. of concentrated sulphuric acid) was added slowly with stirring to a cooled solution of potassium nickelocyanide (prepared from 35 g. of potassium cyanide in 150 c.c. of water, and 16·5 g. of nickel chloride, or 30 g. of nickel sulphate, in 50 c.c. of water) containing 300 c.c. of water and 150 g. of anhydrous sodium carbonate. During the addition a further 300 c.c. of water and sodium carbonate (about 50 g.) were added until the reaction mixture was neutral, and the temperature was allowed to rise to 30—35°. The mixture was stirred at 90° for ½ hour and cooled and the solid separated by filtration was washed with warm water, then with sodium hydroxide solution and water, dried, refluxed with light petroleum (b. p. 60—80°—to remove any *m*-dinitrobenzene), and crystallised from alcohol, giving 2 : 4-dinitrobenzonitrile, m. p. 103—104° (Friedländer and Cohn, *Sitz. Wien. Akad.*, 1902, **111**, 437, give m. p. 103—104°), in 85% yield.

2 : 4-Dinitrobenzonitrile (4 g.), water (6 c.c.), and concentrated sulphuric acid (12 c.c.) were refluxed for ½ hour, water (6 c.c.) added, and the suspension stirred while a solution of sodium nitrite (1 g.) was run in. The cooled liquid was filtered and extracted with ether. The extract was shaken with sodium carbonate solution, which was then used to dissolve the filtered acid. Acidification of the sodium salt solution gave 2 : 4-dinitrobenzoic acid, m. p. 179—180° (Curtius and Bollenbach give m. p. 180°), in 95% yield.

The author is grateful to the Chemical Society for a grant.—THE UNIVERSITY, GLASGOW. [*Received, August 10th*, 1937.]

OBITUARY NOTICES.

JOHN GIBSON.

1871—1936.

JOHN GIBSON, who was born at Hexham on July 12th, 1871, was the son of John P. Gibson. He was educated at the Queen Elizabeth Grammar School, Hexham, and at the North-Eastern County School, Barnard Castle. On leaving school, he entered his father's business "The Old Pharmacy," at Hexham, a business founded by his grandfather in the reign of King William IV, of which he subsequently became sole proprietor. He passed the Minor examination of the Pharmaceutical Society and was registered as a Chemist and Druggist in 1895. He was elected a Fellow of the British Optical Association, and was granted the Freedom of the City of London on being elected a Fellow of the Worshipful Company of Spectaclemakers.

A man of charming personality and of a lovable and generous disposition, Gibson was popular among a wide circle of friends. Though closely engaged in business, he was catholic in his interests, following his father in specialising in photography and archæology. He was elected a Fellow of the Society of Antiquaries of London and of Scotland, and was the author of books dealing with the history of the Priory Church of St. Andrew. His services as a lecturer on subjects of antiquarian interest were eagerly sought after; he broadcast on several occasions on the Priory Churches of the North of England and South of Scotland, and was a member of the Northumberland County History Committee.

Gibson evinced a keen interest in local affairs, becoming a Trustee of the Savings Bank, and Chairman of Managers of the Hexham Council School, in addition to holding other offices.

He died after a short illness on April 21st, 1936, leaving a widow, two sons, and a daughter and a large circle of friends to mourn his loss.

John Gibson was elected a Fellow of The Chemical Society on December 6th, 1900.

G. F. MERSON.

WILHELM GLUUD.

1887—1936.

WILHELM GLUUD was born in Bremen on April 12th, 1887, his father being a Bank Director in that town; his family was of Danish origin. Gluud was educated from 1896—1905 at the Oberrealschule at Bremen, and proceeded from there to the Universities of Munich, Freiburg, and finally Berlin, where he graduated. From 1910—14 he worked at the Davy-Faraday Laboratory, and from 1915—18 he was Assistant and Scientific Research worker at the Kaiser Wilhelm Institute for Coal Research at Mülheim/Rhur. In 1916 he joined the University of Münster, and became Ausserordentlich Professor in April, 1928.

During his life Gluud published a large number of publications in book form, as well as many technical papers relating to his special subject of coal research. For example, in 1919—20 he issued a book on the "High Temperature Coking of Coal," and in 1927—28 he published his book on "Coking," which has been translated into English and into Russian. In spite of his many activities, illustrated by his numerous publications in the technical press, he also published by himself, and with collaborators, some ten scientific papers in the *Berichte* of the German Chemical Society.

By the death of Gluud the German coal industry has lost a distinguished technologist, and one under whose guidance and help many new methods were introduced.

J. F. THORPE.

ARTHUR ROBERT LING.

1861—1937.

LING received his early education privately. For a time he assisted his father in a pharmaceutical chemist's business at Esher, but he soon realised his interests were scientific rather than commercial. Whilst an assistant chemist at the Beetroot Sugar Association he became in 1883 one of the first evening class students at the Finsbury Technical College. With Professor H. E. Armstrong as his mentor Ling made rapid progress and soon became imbued with the spirit of research. His early contributions to the *Journal* comprised a series of papers on the halogenated nitrophenols and halogen derivatives of quinone and quinhydrone.

In 1891 the writer joined Ling, and an intensive period of research work on halogenated quinones and the amyloclastic products of starch hydrolysis followed. Ling was a prodigious worker and his enthusiasm for chemistry was infectious. His literary ability was of a high order, due in no small measure to the then editor of the *Journal*, Charles Groves. Groves was a stylist, to whom his abstractors, Ling being one of them, owed much.

In 1895 Ling was appointed editor of the *Journal* of the Federated Institutes of Brewing, and for 25 years he devoted a great amount of time and care to his editorial duties. For many years he wrote all the abstracts himself and only those who have been engaged on such work can appreciate what that meant. The *Journal*, under Ling's able editorship, soon became the leading publication of the technical and scientific aspects of the fermentation industries, and the Institute fittingly recognised his editorial and other services to brewing by electing him an honorary member in 1934.

In 1898 Ling became a partner with Newlands Brothers, a firm of consulting chemists, and some five years later he started a practice of his own. From then on to 1920 his output of work was remarkable. He re-wrote Sykes' "Hand-Book of Brewing," was technical adviser and a contributor to the *Brewers' Journal*, and communicated many original papers to our own and other Journals. For many years he was lecturer on the Fermentation Industries at the Sir John Cass Institute.

The technical side of the sugar industry, particularly sugar derived from beet, greatly interested Ling, and a report prepared by him as Chairman of the Empire Sugar Supply Committee (*J. Soc. Chem. Ind.*, 1919, 285—306) was a document which played a part in the sugar policy of this country.

In March, 1920, he was appointed to the Adrian Brown chair of Malting and Brewing at Birmingham University, and thus attained, though somewhat late in life, a position to which he was by nature suited. He carried out his academic duties with characteristic energy. Although not a brilliant lecturer, he was a sound and painstaking teacher; the responsive student became imbued with an enthusiasm for his subject, and there is no doubt that Ling exercised a considerable influence on the younger generation of brewers in this country. When he retired from the Chair in 1931 the Senate of Birmingham University conferred on him the title of Emeritus Professor.

A steady flow of research work emanated from his laboratories. Previously he had contributed many useful papers on the analysis of sugars and brewing materials, and had enunciated ideas and suggestions relative to malting and brewing practice. His abiding interest, however, lay in the chemical constitution of the starch molecule. It is with the amyloclastic degradation of starch that his name, like those of O'Sullivan, Lintner, Brown, Morris, Millar and others, will be associated.

In 1895 Ling and Baker showed that Lintner's *iso*maltose obtained from starch was not homogeneous, but a mixture of maltose and a simple dextrin. Two years later maltodextrin-α and maltodextrin-β were separated from starch conversions. Ling in conjunction with Davis continued his work on the action of malt amylase on starch and showed how it was possible by the prolonged action of that enzyme to produce maltose only. The observation was new to the starch problem, for hitherto the idea that there was a resting stage in the hydrolysis of starch (the well-known "No. 8 equation" of Brown and Morris) had been unassailed.

In 1923 Ling and Nanji held the view that the starch granule consisted of two or more substances differing in chemical constitution. Like Maquenne and Roux, they distinguished between amylose, of which most of the internal matter of the starch granule is composed, and amylopectin, which forms the envelope of the granule, the former being more easily attacked by malt amylase than the latter. They found that the product obtained by J. L. Baker in 1902, resulting from the action of barley amylase on starch and termed by him α-amylodextrin, was derived from the amylopectin constituent of the starch. Ling and Nanji regarded this α-amylodextrin, which they re-named α-hexa-amylose, as the basal unit from which amylopectin is built up. When submitted to the action of malt amylase, it was stated to yield a trisaccharide $C_{18}H_{32}O_{16}$, which broke down into dextrose and maltose when acted on by emulsin, and when hydrolysed by yeast maltase or malt amylase, yielded dextrose and *iso*maltose. Thus *iso*maltose, which was stated to be the β form of maltose, came into the picture again. However, in a paper published only a few weeks ago in *Chemistry and Industry*, Ling withdrew this statement, as it was incompatible with the work of Haworth and Long, who had shown that the β form of maltose was cellobiose. He was unable to repeat his former experiments on the conversion of *iso*maltose by emulsin into glucose. His amended conception of *iso*maltose was that it consisted of a mixture of 80% maltose and 20% α-dihexosan. It may well be that the emulsin used in the early experiments contained amylase. Having regard to the composite nature of some of these enzyme preparations, of which we are more aware to-day than in 1922, it is possible that Ling and Nanji's results might be reproduced if similar enzyme preparations were used, but the explanation in the light of this knowledge might be different.

After the publication of his paper in 1923 which, at that time, apparently formulated a reasonable idea for the constitution of starch, Ling extended his investigations to the closely related glycogen. In association with Nanji and Paton a process was described for obtaining pure glycogen from yeast. A method was put forward whereby glycogen and mannan—another polysaccharide which accompanies it in yeast—could be estimated with accuracy, and by it they followed the changes in glycogen and mannan in yeast during the fermentation process. The same authors also made a study of pectinogen and showed how a product could be obtained from apples containing 95% of the theoretical quantity of calcium pectate. It was submitted that the relation of pectinogen to pectic acid is one of esterification, pectinogens being methyl esters of pectic acid.

In addition to his purely scientific work Ling made many analytical and technical contributions to the malting and brewing industries. He investigated the changes which take place during the malting process, the production of diastase during flooring, and, in contra-distinction to Brown and Morris, showed that the cell walls surrounding the starch aggregates in the endosperm of the barley corn were not dissolved during malting, but were practically continuous throughout the whole of the endosperm. In 1914 Ling and Wooldridge devised an improved process of brewing, the novelty of which depended on the boiling and cooling of wort in a closed vessel under a continually diminishing pressure. In the patent literature his name appears in connection with processes for fermenting starch mashes, improvements in yields of alcohol based on the combined action of the enzymes of malt and of certain moulds and yeasts, and the preparation of maltose and other substances from starch.

No major industry has guarded its mysteries in the manner that brewing has. Whilst the mechanism of fermentation is understood, our knowledge of the products of enzymic degradation of starch as they occur in the mash tun have advanced but little during the last four decades. To this little Ling has added his quota.

He was an enthusiast and possessed an extraordinary knowledge of the literature of the various subjects he worked at. By nature he was kindly and courteous, and although inclined to be dogmatic and critical in his opinions of men and affairs, he was never malicious or carping in his spoken or written word.

Julian L. Baker.

MARIUS MAXWELL.

1887—1936.

THE news of Marius Maxwell's death through an aeroplane accident in the south of France last November came as a great shock to his many friends and admirers. Marius was born in 1887, the second son of the late William Maxwell, the well-known engineer and sugar machinery expert of Glasgow and Djokjakarta. Together with his elder brother, Francis, he studied mechanical engineering at the Polytechnikum in Zürich (now known as the Eidgenössische Technische Hochschule), which was enjoying an unparalleled " Blütezeit " under the influence of men like Weiss, Weber, Willstätter, Berl, Lunge, Bredig, Stodola, Treadwell, Werner, Schröter, Einstein, Heim and Rölli.

A friendship soon sprang up between the Maxwells and the late Richard Vernon and the writer, both freshmen in the chemistry department—a friendship soon to be firmly cemented by difficulties faced in unity. One of Maxwell's most endearing qualities was his readiness to champion the weak. It was his blunt disapproval of the arrogant and repressive tactics indulged in by certain organised student groups which led to the first of several encounters needed to clear the air. The authorities, relieved to see an end approaching to what had long been a real difficulty, displayed the necessary tact, and under Maxwell's generalship there was gradually born that era of safe and peaceful dullness in mundane student life which, to judge from a recent visit, endures to this day.

After graduating, Marius left Zürich to enter upon an industrial career and, like his elder brother, quickly won international recognition as an expert in the manufacture of cane sugar; he was later responsible for the design and erection of several important sugar mills in India. Though a keen sportsman, Maxwell soon tired of big game shooting to become a pioneer of the photography of wild life. In this difficult and dangerous pursuit, Maxwell's cool courage and drive, his extraordinary presence of mind and powers of concentration brought him unparalleled success. His close-ups of buffaloes and elephants, for example, are unsurpassed. In his now classic book, " Stalking Big Game in Equatorial Africa " (Heinemann), Maxwell has also recorded many new observations and has welded these into a coherent and enthralling story of the habits and lives of wild animals.

It was probably more his love of wild life, rather than the temporary decline of the sugar industry, which led Maxwell to take up coffee planting in Kenya, where his energy and scientific planning again brought success.

With all his courage and intrepidity, his energy and restless activity, Maxwell was by nature modest and retiring and could seldom be persuaded to speak of his exploits; but when felt called upon to defend a cause he was fearless and outspoken. The traducer met with short shrift at his hands. He was straightforward in all his dealings and absolutely honest and generous in everything he did; his friends were also his admirers and were deeply attached to him.

In 1929 Marius Maxwell married Miss Winifred Ramsay, who accompanied him on his recent journeys and who was with him in Nice at the time of his death.

G. I. FINCH.

FREDERICK VALENTINE RAMSDEN.

1884—1937.

RAMSDEN was born in Australia in 1884 and was educated at the Melbourne Grammar School. He took up chemistry as a career, and as a young man joined the staff of the Victoria Geological Survey. In 1907 he received an appointment in the Assay Office of the Royal Mint, Melbourne, and remained there until 1921. In that year the Rand Refinery, Limited, commenced operations in Germiston (South Africa) and Ramsden was appointed Chief Assayer, a position he held until the time of his death, which took place in London on April 22nd, 1937.

Ramsden was elected a Fellow of the Chemical Society on December 1st, 1910; he was also a member of the Australian Chemical Institute, of the Institute of Metals and of other scientific bodies.

FRANK LITHERLAND TEED.

1858—1937.

Frank Litherland Teed died at his home at Tonbridge on April 22nd last in his 79th year. He was born on May 16th, 1858, and received his education and scientific training in Germany and at University School and College, London, and in Edinburgh. He obtained the degree of D.Sc. (Lond.), afterwards becoming a Barrister at Law at Middle Temple. He was elected to the Fellowship of the Institute of Chemistry in 1888 and was a Member of the Institute of Mining and Metallurgy.

In 1883 Teed married the daughter of the late W. L. Windus, the pre-Raphaelite artist. They had three children : one died in infancy, another, an officer in the Royal Navy, was unfortunately drowned whilst serving in a destroyer, and one, a son, survives him. His wife predeceased him in 1935.

Teed was for many years Public Analyst for the City of London and the Metropolitan Boroughs of Islington and Camberwell; he retired from these offices in 1923. It was in carrying out his official duties that he made notable contributions to the proper definition of brandy and whisky, which subsequently resulted in the appointment of a Royal Commission to report on the subject. Among his various contributions to science was a paper, read before the Society in 1885, on the " Decomposition of Potassium Chlorate by Heat " and another, " Note on the Decomposition of Ammonium Chloride Solution by Calcium Carbonate," to the Society of Chemical Industry. He also introduced a test for lead, and in conjunction with Sulman he invented the bromo-cyanide process for the extraction of gold from its ores, which still finds application in the treatment of telluride ores. After his retirement he published two monographs, " Volume Alterations on and in Solution " in 1926, and " *Torricelli contra Mundum* " in 1931.

All his life Teed was a great sailor, preferably in small boats. He took no special interest in the racing side of sailing, but many of his friends were glad to accept his invitation to spend pleasurable week-ends cruising with him at Southampton. Amongst his notable achievements may be mentioned his sail in an open boat from Southampton to Rochester, when he was well over 60, accompanied only by a friend of about the same age.

Teed was very happy in his retirement and never ceased to take an active interest in general affairs. Until shortly before his death he came to Town to his club and the theatre and visited his friends in quiet contentment, notwithstanding the fact that during the last three years, owing to the state of his heart, his hold on life was distinctly precarious. He was a man of great kindness of heart and always did his best to help those who went to him for guidance. In addition to his kindly nature he had a quiet charm of manner which inspired in those who knew him intimately a feeling of affectionate regard.

J. Kear Colwell.

LUDWIG WOLF.

1891—1937.

Ludwig Wolf was born on July 5th, 1891, at Rozsaszentmarton, Hungary. In 1909 he entered the Technische Hochschule, Berlin, where he passed the Diploma examination in 1913 and graduated as Dr. Ing. in 1915. He became assistant to Professor K. A. Hofmann in the Inorganic Chemical Institute of Berlin University in 1914, but returned to Austria in 1915 to take up military service in the Imperial Air Force. Demobilised in 1919, he became (in the same year) assistant to Professor Schlenk in the second Chemical Institute of the University of Vienna, where he graduated as Dr. Phil. in 1921. When Professor Schlenk was called to Berlin University in 1921, Dr. Wolf accompanied him as assistant in the Chemical Institute. He became Privatdozent in 1925, and in 1931 extra-ordinary Professor. On October 1st, 1933, he was compulsorily retired in accordance with Article 3 of the new Law for the Reconstitution of the Professional Services. After a short period of research work in the Chemical Laboratory of University College, London, he went to India in 1934 as Professor of Chemistry at Andhra University, Waltair. After a relatively

short time in India he was forced by bad health to return to Europe for special medical treatment, but unfortunately his health became progressively worse. He died in Budapest on May, 31st, 1937.

Professor Wolf's scientific work was concerned with (a) the allotropy of phosphorus and the chemistry of the oxides and acids of that element; (b) the determination of hydrogen-ion concentration in weakly buffered systems; (c) the chemistry of clay, the rôle of clay in cultivated soils and its influence on plant growth; (d) various problems in agricultural chemistry, including the influence of small quantities of certain rarer elements on the growth of plants. He wrote a textbook of Inorganic Chemistry in 1924 (2nd edition, 1931).

During his life he worked in close contact with industry. He was an excellent University teacher and organiser of students' work. Had he been able to continue his career in Berlin University, it is understood that he would soon have succeeded to the Directorship of the Inorganic Analytical Section of the Berlin Chemical Institute.

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F. G. Donnan.

LEROY WILEY McCAY.

1857—1937.

We record with sorrow the death on April 13th, 1937, of Leroy Wiley McCay, Professor of Chemistry, Emeritus, at Princeton University, U.S.A.

McCay was born at Rome, Georgia, on August 9th, 1857, and spent his early years on one of his family's plantations in Alabama; after the Civil War, he was sent to school in the North. From 1873 to 1875 he continued his schooling in Dresden, Germany, and there became so fond of music that he returned to Baltimore filled with the idea of becoming a professional musician. This idea was frowned upon by his father, a disciplinarian of strong Scottish heredity, and the boy was sent to Princeton College in 1875. Here he pursued a classical course, which he praised to the end of his days, and graduated A.B. in 1878 with distinction, delivering the modern language oration of that year.

The next four years he spent again in Germany, first at Freiberg in Saxony, where he came under the influence of Winkler, and later at Heidelberg under Bunsen. Here he acquired his training in and love for analysis.

He graduated A.M. Princeton in 1881 and Sc.D. in 1883, was appointed to his first teaching position there in the same year, and became Professor of Inorganic Chemistry in 1892. His active service to Princeton as a teacher and investigator thus extended over 45 years, 1883 to 1928, when he retired; while his association with Princeton, first as a student and last as a professor emeritus, covered a period of nearly sixty years.

Until the last few years, when his health failed, McCay was indefatigably active in investigative work, chiefly in inorganic and in analytical chemistry; in these he was universally recognised as an outstanding worker, both at home and abroad: the chemistry of the elements arsenic, antimony, tin, tungsten, molybdenum, and platinum is but one of the fields that he enriched by his contributions. Each of his more than fifty articles, published in American, English, and German scientific journals, demanded hundreds of hours of careful work in the laboratory. From this exacting work he found relaxation in literature, both classical and modern, and in music. As a student he had founded and conducted a student orchestra, and, as a faculty member, a faculty orchestra. He was appreciative of art as well as of science. While his analytical work made him an exact man, his extensive reading made him what Bacon called a full man, and his extraordinary facility in conversation made him a ready man.

From 1914 to 1922 McCay served as Chairman of the Department of Chemistry at Princeton University. In this capacity he kept the affection of students and colleagues alike by his constant accessibility. During this period his brilliant oratory was often requisitioned in placing before the alumni and others the crying need for a new chemical laboratory, a project which has since been realised and in whose planning he took an impor-

tant part. Most appropriately, he became the first incumbent of the new chair of chemistry endowed in memory of his old friend Russell Wellman Moore.

Among his assets as a teacher were a resonant voice, a faculty for visualisation and dramatisation, boundless enthusiasm, a philosophy of optimism, and a strong sense of humour. He endeared himself to those who knew him because, as a man, he was modest, loyal, and full of friendliness.

ALAN W. C. MENZIES.

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367. *The Dehydration of* r-2-*Phenyl*-1-o-, -m-, *and* -p-*tolyl*-1-*ethylethylene Glycols* (α-*Forms*).

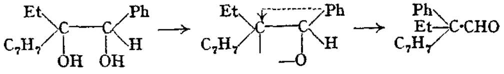
By ROBERT ROGER and ALEXANDER M. ROBERTS.

The dehydration of the *r*-2-*phenyl*-1-o-, -m-, and -p-*tolyl*-1-*ethylethylene glycols* (α-forms) is described. All three glycols give aldehydes with dilute sulphuric acid or oxalic acid by semihydrobenzoin transformation. With concentrated sulphuric acid, the *o*- and the *m*-glycol give the corresponding *tolyl α-phenylpropyl ketones* by semipinacolinic transformation. The migration of the ethyl group is unexpected, and shows that transformations previously termed vinyl may really have been semipinacolinic in character. The results of the transformation of the aldehydes and the direct dehydration of the glycols with concentrated sulphuric acid are compared.

THE dehydration of *r*-*p*-tolylhydrobenzoin (α-form) was first investigated by McKenzie, Mills, and Myles (*Ber.*, 1930, **63**, 904). The study was extended by McKenzie, Roger, and McKay (J., 1932, 2597) (see also Koelsch, *J. Amer. Chem. Soc.*, 1932, **54**, 2049) to the optically active form of the glycol. Roger and McKay (J., 1933, 332) made a comparative study of the *o*-, *m*-, and *p*-tolylhydrobenzoins and found that, with dilute sulphuric acid, *r*-*o*-tolylhydrobenzoin gave a mixture of *r*-*o*-tolyldeoxybenzoin and diphenyl-*o*-tolylacetaldehyde, whilst the *m*- and *p*-isomers gave the corresponding deoxybenzoins and only traces of the aldehydes. This difference became more striking when the optically active forms of these glycols were dehydrated with dilute sulphuric acid, since the *o*-glycol gave almost pure optically active *o*-tolyldeoxybenzoin, but the *m*- and *p*-glycols gave deoxybenzoins which were almost optically inactive. At that time, the authors were inclined to the view that the *o*-ketone had been formed by semihydrobenzoin migration of hydrogen (*e.g.*, Scheme II), but that the *m*- and *p*-ketones had been formed by vinyl dehydration (*e.g.*, Scheme III). The only other explanation that can be offered is that the *m*- and *p*-tolyldeoxybenzoins are formed through the aldehydes as intermediates. These aldehydes contain no centre of asymmetry and, therefore, in transformation could not give optically active ketones. There was thus ambiguity as to the mechanism of formation of the *m*- and *p*-tolyldeoxybenzoins.

Phenylpropionylcarbinol can give rise to glycols which contain two centres of asymmetry and in which all the hydrocarbon radicals may be different. For instance, with the tolylmagnesium bromides, the glycols $C_6H_4Me\cdot CEt(OH)\cdot CHPh(OH)$ were obtained, and their dehydration was interesting from three points of view. With dilute acid, they gave aldehydes

Scheme I.



in each case. These would arise by the semihydrobenzoin migration of phenyl (Scheme I). The mechanism of dehydration being the same for each glycol, the ambiguity of mechanism which arose in the formation of the tolyldeoxybenzoins from the respective tolylhydrobenzoins is removed. Secondly, the transformation of the aldehydes into ketones was studied, and compared with the results of the direct dehydrations of the glycols.

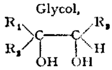
Thirdly, the results contrast with the dehydration of ethylhydrobenzoin and throw light on the problem of " vinyl dehydration."

With dilute sulphuric acid no appreciable amounts of ketones or oxides could be detected, whereas ethylhydrobenzoin can give rise to either diphenylethylacetaldehyde, diphenylbutanone, or a diethylenic oxide on dehydration with dilute sulphuric acid under different experimental conditions (Tiffeneau and Dorlencourt, *Ann. Chim. Phys.*, 1909, **16**, 237; Lévy, *Bull. Soc. chim.*, 1921, **29**, 865; McKenzie and Roger, J., **1924**, **125**, 2148). It would seem that the presence of the *o*-, *m*-, and *p*-tolyl groups, therefore, causes a certain bias in favour of aldehyde formation (semihydrobenzoin transformation), and the saturation capacities of Et + C_7H_7(*o*-, *m*-, or *p*-) must be definitely greater than those of Ph + H. *o*-Tolylhydrobenzoin was the only one of the three isomers from which the formation of aldehyde was definitely detected. The alteration in trend of the dehydrations of different trisubstituted ethylene glycols of the type $CR_1R_2(OH)\cdot CHAr(OH)$ with dilute sulphuric acid or oxalic acid is shown in Table I.

TABLE I.

Dehydration of glycols by dilute sulphuric acid or oxalic acid.

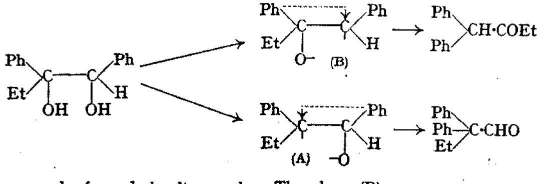
Glycol,



No.	R_1.	R_2.	R_3.	Product.	Mechanism of formation. Type.*	Migrtn. of
1	Ph	Et	Ph	Diphenylethylacetaldehyde	A	Ph
				Diethylene oxide	—	—
				Diphenylbutanone	B	Ph
2	Ph	Me	Ph	Diphenylmethylacetaldehyde	A	Ph
				Diethylene oxide	—	—
3	*o*-C_7H_7	Et	Ph	Phenyl-*o*-tolylethylacetaldehyde	A	Ph
4	*m*-C_7H_7	Et	Ph	Phenyl-*m*-tolylethylacetaldehyde	A	Ph
5	*p*-C_7H_7	Et	Ph	Phenyl-*p*-tolylethylacetaldehyde	A	Ph
6	Ph	Ph	*o*-C_7H_7	Diphenyl-*o*-tolylacetaldehyde	A	*o*-C_7H_7
				Diphenylmethyl *o*-tolyl ketone	A	H
7	Ph	Ph	Ph	Triphenylacetaldehyde	A	Ph
				Phenyldeoxybenzoin	A or C?	H
8	Ph	*o*-C_7H_7	Ph	Diphenyl-*o*-tolylacetaldehyde	A	Ph
				o-Tolyldeoxybenzoin	A or C?	H
9	Ph	*m*-C_7H_7	Ph	Diphenyl-*m*-tolylacetaldehyde (trace)	A	Ph
				m-Tolyldeoxybenzoin	A or C?	H
10	Ph	*p*-C_7H_7	Ph	Diphenyl-*p*-tolylacetaldehyde (trace)	A	Ph
				p-Tolyldeoxybenzoin	A or C?	H

* A = Semihydrobenzoin. B = Semipinacolinic. C = Vinyl.

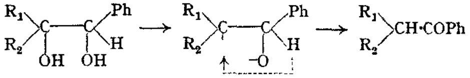
This table shows the gradation in the dehydration mechanism of such a series of glycols according to the saturation capacities of the groups involved. In example (1) the relationship Ph + Et = Ph + H holds and the result is that the two possible intermediate



complexes may be formed simultaneously. The phase (B) rearranges to give diphenylbutanone, whilst (A) gives diphenylethylacetaldehyde; the combination of (A) and (B)

would give the diethylene oxide. In examples 2, 3, 4, and 5, Ph + Me or C_7H_7(*o*-, *m*-, or *p*-) + Et > Ph + H, but not to a large extent, and the result seems to be the exclusive formation of the aldehyde by semihydrobenzoin migration of Ph. Examples 6, 7, and 8 are particularly interesting since they form a " transition period " in the table. Here the relationship Ph + Ph or C_7H_7(*o*-, *m*-, or *p*-) > Ph + H or *o*-C_7H_7 + H is quite definite but not so marked as in cases 9 and 10. As a result of this, in cases 6, 7, and 8, aldehydes are formed by semihydrobenzoin migration of an aryl group, but simultaneously ketones are formed by competitive semihydrobenzoin migration of hydrogen. In cases 9 and 10, the disparity in the relationship Ph + C_7H_7(*m*- or *p*-) > Ph + H is so large, and the residual affinity of the receptor carbon atom so small, as to ensure exclusive formation of ketones, probably by semihydrobenzoin migration of hydrogen as in Scheme II (Roger and McKay, *loc. cit.*; Lagrave, *Ann. Chim.*, 1927, **8**, 363).

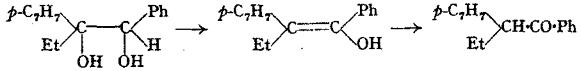
Scheme II.



These considerations have an important bearing on the saturation capacity of the *o*-tolyl group. At the time, Roger and McKay (*loc. cit.*), in considering the results of dehydration of *o*-tolylhydrobenzoin, could not exclude the possibility that the *o*-tolyl group had a very small saturation capacity and, therefore, that *o*-tolyldeoxybenzoin had been formed by semipinacolinic migration of the *o*-tolyl group. The fact that optically active *o*-tolyldeoxybenzoin was obtained from the (+)*o*-tolylhydrobenzoin lent a certain support to this hypothesis, since it had been previously shown that optical activity could be maintained during semipinacolinic transformation (McKenzie and Dennler, *Ber.*, 1927, **60**, 220; Roger and McKenzie, *Ber.*, 1929, **62**, 272). Roger and Harper (*Rec. trav. chim.*, 1937, **56**, 202), as a result of a study of the dehydration of 2 : 2-diphenyl-1-*o*-tolylethylene glycol, concluded that the saturation capacity of the *o*-tolyl group could not differ much from that of the phenyl group. The results of the dehydration of the three glycols now described show that the saturation capacity of the *o*-tolyl group is probably greater than that of phenyl; otherwise, there would not be exclusive formation of the aldehyde by the action of dilute sulphuric acid or molten oxalic acid.

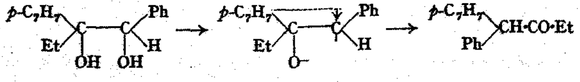
It will be noted from the table that the formation of ketones in certain cases is ascribed to either semihydrobenzoin migration of hydrogen or vinyl dehydration. It seems to us that with dilute acid the vinyl dehydration mechanism is not generally suitable. Indeed, in certain cases, such as the formation of pure optically active *o*-tolyldeoxybenzoin from *o*-tolylhydrobenzoin, the mechanism is inadmissible. This point will be dealt with more fully in a later communication.

Scheme III.

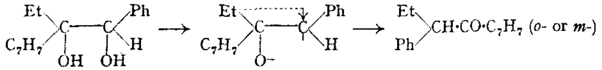


Dehydration with concentrated sulphuric acid of the three glycols described showed that here there was no common trend in mechanism. The *p*-glycol yielded *α-p-tolylbutyrophenone* [through the semihydrobenzoin migration of H (*e.g.*, Scheme II) or by vinyl dehydration (Scheme III)] and phenyl-*p*-tolylmethyl ethyl ketone [by semipinacolinic migration

Scheme IV.



of the *p*-tolyl group (Scheme IV)]. On the other hand, the *o*- and the *m*-glycol gave the unusual result that in each case the ethyl group had migrated (by semipinacolinic transformation) *in preference to the tolyl group with the formation of o- or m-tolyl α-phenylpropyl ketone, although it is generally accepted that the aryl migrates in preference to the alkyl group* (Tiffeneau and Lévy, *Bull. Soc. chim.*, 1931, **49**, 1661) :



Now the formation of ethyldeoxybenzoin from ethylhydrobenzoin (with concentrated sulphuric acid) has always previously been considered to be the result of vinyl dehydration (*e.g.*, Scheme III). The detection of the migration of the ethyl group in the cases recorded here has only been rendered possible by the fact that the two aryl groups attached to the skeleton carbon atoms of the glycol are not identical as in the case of ethylhydrobenzoin. The formation of alkyldeoxybenzoins, therefore, from the corresponding alkylhydrobenzoins under these conditions (Orékhoff, *Bull. Soc. chim.*, 1919, **25**, 182; Billard, *ibid.*, 1921, **29**, 429; Tiffeneau and Orékhoff, *ibid.*, 1923, **33**, 195) can now be considered to be the *result of semipinacolinic migration of an alkyl group and not of vinyl dehydration.* Table II shows the results recorded for the dehydration with concentrated sulphuric acid of the same glycols as in Table I, and also, where the data are available, the transformations of the corresponding aldehydes.

TABLE II.

Dehydration of glycols with concentrated sulphuric acid.

Glycol (see Table I).	Product of dehydration.	Mechanism. Type.*	Mechanism. Migrtn. of	Transformation of aldehyde : product.
1	Ethyldeoxybenzoin	A or C ? or B	H Et	Ethyldeoxybenzoin and diphenylbutanone
	Diphenylbutanone	B	Ph	
2	Methyldeoxybenzoin	A or C ? or B	H Me	Methyldeoxybenzoin
	Diphenylacetone (trace)	B	Ph	
3	*o*-Tolyl α-phenylpropyl ketone	B	Et	*o*-Tolyl α-phenylpropyl ketone
4	*m*-Tolyl α-phenylpropyl ketone	B	Et	α-*m*-Tolylbutyrophenone
5	α-*p*-Tolylbutyrophenone	A or C ?	H	α-*p*-Tolylbutyrophenone
	Phenyl-*p*-tolylmethyl ethyl ketone	B	*p*-C_7H_7	Phenyl-*p*-tolylmethyl ethyl ketone
6	Diphenylmethyl *o*-tolyl ketone	A or C ?	H	See 8
7	Phenyldeoxybenzoin	A or C ?	H	Phenyldeoxybenzoin
8	*o*-Tolyldeoxybenzoin	A	H	*o*-Tolyldeoxybenzoin and diphenylmethyl *o*-tolyl ketone
	Diphenylmethyl *o*-tolyl ketone	Trans. of aldehyde ?		
9	*m*-Tolyldeoxybenzoin	A or C ?	H	—
	Diphenylmethyl m-tolyl ketone (trace)	*Trans. of aldehyde ?*		
10	*p*-Tolyldeoxybenzoin	A or C ?	H	—
	Diphenylmethyl *p*-tolyl ketone (trace)	Trans. of aldehyde ?		

* See Table I.

It will be seen that certain glycols recorded in the table underwent semipinacolinic transformation. In most cases also, ketones arise by vinyl dehydration or the alternative semihydrobenzoin migration of hydrogen. The transformations of the aldehydes, where they have been isolated, would support the theory of Danilov that the aldehydes form the intermediate phase in glycol dehydration; but 2-phenyl-1-*m*-tolyl-1-ethylethylene glycol (α-form) is an exception, for apparently a different ketone from that obtained by the direct dehydration of the glycol was isolated. In this case, however, both the glycol and the aldehyde gave small amounts of the same sulphur-containing compound accompanying

the ketonic products, and the total yield was very poor, much of the glycol and aldehyde being unaccounted for in the transformations.

From this result and previously known cases (Tiffeneau, Lévy, and Weill, *Bull. Soc. chim.*, 1931, **49**, 1606; Lévy and Pernot, *ibid.*, p. 1721), it will be seen, however, that the conception of the aldehyde as the intermediate phase is only applicable to certain cases of glycol dehydration with concentrated sulphuric acid and cannot be accepted as general. It must be noted, however, that in dehydration or transformation with concentrated sulphuric acid, the results tend to be irregular (*e.g.*, the dehydration of *p*-tolylhydrobenzoin with concentrated sulphuric acid: Koelsch, *loc. cit.*; McKenzie, Mills, and Myles, *loc. cit.*; McKenzie, Roger, and McKay, *loc. cit.*), and the yields are often meagre. The actual isolation, in some cases, of compounds containing sulphur may explain this loss to a certain extent. These factors render it difficult to make rigid conclusions from such experiments.

Experimental.

r-2-*Phenyl*-1-p-*tolyl*-1-*ethylethylene Glycol* (α-*form*).

Preparation.—Phenylpropionylcarbinol (15 g., 1 mol.) was added to the Grignard reagent prepared from *p*-bromotoluene (48 g., 3 mols.). After 5 hours' boiling, the mixture was decomposed with ice and dilute sulphuric acid. From the ethereal layer a white solid (13·6 g., m. p. 97—100°) was obtained. The *glycol* (α-form) separated from light petroleum in hexagonal plates, m. p. 100—101° (Found: C, 79·9; H, 8·0. $C_{17}H_{20}O_2$ requires C, 79·6; H, 7·9%).

Dehydration with Concentrated Sulphuric Acid.—Finely pulverised glycol (10 g.) was added in small amounts to concentrated sulphuric acid (25 c.c.) and triturated intermittently for 19 hours. The mixture was poured into ice and water, and extracted with ether. From the ethereal extract, an oil (b. p. 177°/16 mm., 5·2 g.) was obtained. This partly solidified on keeping, and after addition of some light petroleum, the solid was filtered off (1·5 g.) and crystallised from light petroleum, α-p-*tolylbutyrophenone* separating as octahedra, m. p. 54—55° (Found: C, 85·5; H, 7·9. $C_{17}H_{18}O$ requires C, 85·7; H, 7·6%). The residue from the separation of this ketone gave α-p-*tolylbutyrophenonesemicarbazone*, m. p. 160—161° (Found: C, 73·4; H, 7·2. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2%). On hydrolysis with hydrochloric acid (20%), it gave back the solid ketone, m. p. 54—55°. From the mother-liquor of crystallisation of this semicarbazone, the *semicarbazone* of phenyl-*p*-tolylmethyl ethyl ketone (see later) was obtained; it separated from benzene in needles, m. p. 202·5—203·5° (Found: C, 73·5; H, 7·2; N, 14·6. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2; N, 14·2%).

Some of the distilled dehydration product, b. p. 177°/16 mm., was treated with 2 : 4-dinitrophenylhydrazine and only the 2 : 4-dinitrophenylhydrazone of α-*p*-tolylbutyrophenone was isolated; this separated from ethyl alcohol as yellow prisms, m. p. 145·5—146·5° (Found: C, 65·8; H, 5·1. $C_{23}H_{22}O_4N_4$ requires C, 66·0; H, 5·3%). With alcoholic potash (15%), the attempted scission of the ketone mixture from a similar dehydration gave mainly unchanged material.

Dehydration with Dilute Sulphuric Acid.—The glycol (6 g.) was boiled for 5 hours with 25% (by vol.) sulphuric acid. After dilution and extraction with ether, an oil (5·2 g., b. p. 175—181°/22 mm.) was obtained from the extract.

Phenyl-p-*tolylethylacetaldehydesemicarbazone*, m. p. 154—155° (Found: C, 72·9; H, 7·1. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2%), separated from benzene in spear-shaped plates.

This semicarbazone was boiled with 20% hydrochloric acid and afforded *phenyl*-p-*tolylethylacetaldehyde*, b. p. 182—183°/20 mm., $n_{5893}^{19°}$ 1·5742 (Found: C, 85·5; H, 7·6. $C_{17}H_{18}O$ requires C, 85·7; H, 7·6%).

The semicarbazone prepared from this oil had m. p. 154—155°, so no transformation could have occurred in the presence of the acid used for the hydrolysis. *Phenyl*-p-*tolylethylacetaldehyde*-2 : 4-*dinitrophenylhydrazone*, m. p. 162—163°, crystallised from ethyl alcohol–acetone in yellow, rectangular prisms (Found: C, 66·0; H, 5·5. $C_{23}H_{22}O_4N_4$ requires C, 66·0; H, 5·3%), and was also prepared directly from the dehydration product.

Dehydration of the glycol with 20% acid (by vol.) afforded considerable amounts of unchanged glycol together with the aldehyde.

Dehydration with Oxalic Acid.—The glycol (12 g.) was boiled gently with fused hydrated oxalic acid (80 g.) for 7 hours. The product had b. p. 170—173°/17 mm., $n_{5893}^{19°}$ 1·5780 (7·6 g.). The semicarbazone of phenyl-*p*-tolylethylacetaldehyde, m. p. 154—155° (spear-shaped plates from

alcohol or benzene), was obtained, identical with that from the dehydration with dilute sulphuric acid; it also gave the same 2 : 4-dinitrophenylhydrazone, m. p. 162—163°.

Dehydration with Ethereal Hydrogen Chloride.—The glycol (3 g.) in 50 c.c. of dry ether was saturated with dry hydrogen chloride and kept for 2 days at the ordinary temperature. From the ether, an oil (2·75 g.) was obtained, which gave the 2 : 4-dinitrophenylhydrazone of phenyl-*p*-tolylethylacetaldehyde, m. p. 162—163°, identical with that described.

Dehydration with Fuming Hydrochloric Acid.—The glycol (3 g.) was shaken with fuming hydrochloric acid for one week. The oil (2·9 g.) obtained from the ethereal extract gave the same 2 : 4-dinitrophenylhydrazone, m. p. 162—163°.

Dehydration with Sulphuric Acid (d 1·51).—Finely powdered glycol (3·7 g.) was added in small amounts to dilute sulphuric acid (*d* 1·51, 45 c.c.) with intermittent shaking, and kept for 6 days. By extraction with ether, an oil (3·25 g.) was obtained. This deposited unchanged glycol (0·75 g.), which was removed, and from the residue was prepared the semicarbazone of phenyl-*p*-tolylethylacetaldehyde (1 g.), m. p. 154—155°.

The Isomerisation of Phenyl-p-tolylethylacetaldehyde.—The aldehyde (4 g.) was added slowly to concentrated sulphuric acid (10 c.c.) with stirring. After 19 hours, the claret-coloured mixture was poured into ice and water, and extracted with ether. The extract afforded an oil (1·7 g.), which gave a white solid when treated with semicarbazide. Two semicarbazones were separated from the crude product by fractional crystallisation : (a) prisms, m. p. 159·5—160·5°, alone or mixed with the semicarbazone of α-*p*-tolylbutyrophenone; (b) needles, m. p. 202—203°, alone or mixed with the semicarbazone of phenyl-*p*-tolylmethyl ethyl ketone.

Constitution and Syntheses of the Dehydration Products.

Scission of Phenyl-p-tolylethylacetaldehyde.—The aldehyde (5 g.) was boiled with alcoholic potassium hydroxide (30%, 80 c.c.) for 24 hours. Extraction of the diluted alkaline liquors with ether yielded an oil (1·9 g.), b. p. 150—160°/23 mm. This was redistilled and a fraction, b. p. 154—156°/23 mm. ($n_{5893}^{8°}$ 1·5683), obtained (Found : C, 91·2; H, 8·4. $C_{17}H_{18}$ requires C, 91·4; H, 8·6%). This was *α-phenyl-α-p-tolylpropane*. On acidifying the alkaline liquor and extracting it with ether, a small amount of liquid was obtained. This had strong reducing properties, but there was insufficient for definite identification as formic acid. No traces of benzoic or *p*-toluic acids were found.

Oxidation of Phenyl-p-tolylethylacetaldehyde.—Silver oxide and sodium hypobromite did not oxidise the aldehyde; but chromic acid in glacial acetic acid afforded phenyl *p*-tolyl ketone, m. p. 54—55°, and 4-benzoylbenzoic acid, m. p. 193—194° (Found : C, 74·2; H, 4·6. Calc. for $C_{14}H_{10}O_3$: C, 74·3; H, 4·5%) (Zincke, *Annalen*, 1872, **161**, 109, gives m. p. 194°).

Oxidation of the Mixture obtained by Dehydration with Concentrated Sulphuric Acid.—The mixture (4 g.) was added to chromic anhydride (12 g.) in glacial acetic acid (70 c.c.) and boiled gently for 45 minutes. On making the solution alkaline with sodium hydroxide and extracting it with ether, an oil (0·9 g.) was got, but it did not give a semicarbazone. On acidification of the oxidation liquors and re-extraction with ether, a dark oil was obtained after removal of the acetic acid. This gave clusters of colourless needles from aqueous alcohol, m. p. 138—139° (0·2 g.) (Found : C, 75·7; H, 5·9. $C_{17}H_{16}O_3$ requires C, 76·1; H, 6·0%). This *solid* dissolved in cold sodium hydroxide, and analysis indicates that it is derived from either of the ketones in the dehydration mixture by the oxidation of the *p*-methyl substituent to a carboxyl group : it may thus be either $CO_2H{\cdot}C_6H_4{\cdot}CHEt{\cdot}COPh$ or $CO_2H{\cdot}C_6H_4{\cdot}CHPh{\cdot}COEt$.

Synthesis of r-α-p-Tolylbutyrophenone.—(a) *p-Tolylethylcarbinol.* *p*-Tolyl ethyl ketone (40 g.) was reduced with sodium (35 g.) in alcohol (500 c.c.). The carbinol (32 g.) had b. p. 110°/21 mm. (cf. v. Auwers and Kolligs, *Ber.*, 1922, **55**, 43, who give b. p. 114°/12 mm. for a preparation from propaldehyde and *p*-tolylmagnesium bromide). Reduction with sodium amalgam gave *s-p-tolylethylpinacol*, m. p. 101—102° (aggregates of prisms from light petroleum) (Found : C, 80·2; H, 8·7. $C_{20}H_{26}O_2$ requires C, 80·5; H, 8·8%).

(b) *p-Tolylethylchloromethane.* The carbinol (20 g.) was treated with thionyl chloride (50 g.), and after removal of excess of the latter, a colourless *oil*, b. p. 94—95°/15 mm., was obtained; $n_{5893}^{18°}$ 1·5230 (Found : C, 71·5; H, 7·7; Cl, 21·0. $C_{10}H_{13}Cl$ requires C, 71·2; H, 7·8; Cl, 21·1%).

(c) *p-Tolylethylacetonitrile.* The above chloride (10 g.) was heated with mercuric cyanide (30 g.) at 160°. An impure oil was obtained from the benzene extract, which did not yield a sharp-boiling fraction. Similar results were got with mercuric cyanide at 100° and with alcoholic potassium cyanide at 100°. The products contained nitrogen, however.

(d) r-α-*p-Tolylbutyrophenone.* The combined crude product from the above preparation of the nitrile (6·2 g.) was added to the Grignard reagent prepared from bromobenzene (24 g.),

and the mixture boiled for 16 hours. After decomposition with ice and concentrated hydrochloric acid, a solid was obtained from the acid layer. This crystallised from light petroleum in octahedra, m. p. 54—55°, alone or mixed with *r*-α-*p*-tolylbutyrophenone obtained from the dehydration; and it formed a 2 : 4-dinitrophenylhydrazone, m. p. 145·5—146·5°, alone or mixed with the similar compound obtained from the concentrated sulphuric acid dehydration product of the glycol.

Synthesis of Phenyl-p-*tolylmethyl ethyl ketone*. Phenyl-*p*-tolylacetonitrile (McKenzie, Roger, and McKay, J., 1932, 2597) (10 g.) was added to the Grignard reagent prepared from ethyl bromide (21 g.). After 4 hours' boiling and decomposition with ice and dilute sulphuric acid, an oil was obtained from the ethereal layer. This deposited unchanged nitrile (3 g., m. p. 62—63°). The residue was treated with semicarbazide, and fine colourless needles (from benzene), m. p. 203·5°, alone or mixed with the semicarbazone of phenyl-*p*-tolylmethyl ethyl ketone were obtained. No 2 : 4-dinitrophenylhydrazone could be isolated.

r-2-*Phenyl*-1-m-*tolyl*-1-*ethylethylene Glycol* (α-*Form*).

Preparation.—By the action of *m*-tolylmagnesium bromide (from *m*-bromotoluene, 44 g.) on phenylpropionylcarbinol (14 g.), r-2-*phenyl*-1-m-*tolyl*-1-*ethylethylene glycol* (α-form) was obtained (14 g.) as described for the *p*-isomeride. It separated from light petroleum in rosettes of colourless needles, m. p. 101—102° (Found: C, 79·9; H, 7·8. $C_{17}H_{20}O_2$ requires C, 79·6; H, 7·9%).

Dehydration with Concentrated Sulphuric Acid.—The glycol (17 g.) was triturated with concentrated sulphuric acid for 19 hours; a claret coloration developed, and the product was isolated as described for the *p*-glycol. An oil was obtained which, on solution in alcohol, yielded a compound, m. p. 80—83°; recrystallisation from alcohol afforded r-m-*tolyl* α-*phenylpropyl ketone* as octagons, m. p. 82—83° (Found: C, 85·4; H, 7·5. $C_{17}H_{18}O$ requires C, 85·7; H, 7·6%). This ketone did not form a semicarbazone but gave a 2 : 4-*dinitrophenylhydrazone*, m. p. 130—131° (yellow needles from alcohol) (Found: C, 65·8; H, 5·1. $C_{23}H_{22}O_4N_4$ requires C, 66·0; H, 5·3%). From the mother-liquors another compound separated in the form of prisms, m. p. 97—98°, 1·3 g. (after several crystallisations from light petroleum). This solid was saturated, contained sulphur, was insoluble in cold, but slightly soluble in hot sodium hydroxide, and gave no semicarbazone (Found: C, 68·8; H, 5·4%). Its constitution was not determined.

Dehydration with Dilute Sulphuric Acid.—This was carried out as described for the *p*-glycol. The glycol (8 g.) gave a crude oil (7·5 g.), which had b. p. 175—177°/18 mm. and yielded the *semicarbazone* of phenyl-*m*-tolylethylacetaldehyde, m. p. 164—165° (fine needles from benzene) (Found: C, 73·4; H, 7·2. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2%); the 2 : 4-*dinitrophenylhydrazone*, *yellow hexagonal prisms from alcohol-acetone, had m. p. 169·5—170·5° (Found:* C, 66·1; H, 4·9. $C_{23}H_{22}O_4N_4$ requires C, 66·0; H, 5·3%).

Dehydration with Oxalic Acid.—The glycol (16 g.) was dehydrated as described for the *p*-glycol. An oil was obtained, b. p. 175—177°/18 mm., $n_{5893}^{16°}$ 1·5789, 15 g. (crude yield). This gave the semicarbazone, m. p. 164—165°, and the 2 : 4-dinitrophenylhydrazone, m. p. 169·5—170·5°, of phenyl-*m*-tolylethylacetaldehyde identical with those described above.

Isomerisation of Phenyl-m-*tolylethylacetaldehyde*.—The aldehyde (4 g.) was triturated with concentrated sulphuric acid (10 c.c.). A purple coloration developed, and after 19 hours' standing, the product was worked up as described for the *p*-isomer. An oil (1·5 g.) was obtained which did not solidify and was treated with semicarbazide. A small amount of a *semicarbazone*, m. p. 134—135°, probably that of *r*-α-*m*-tolylbutyrophenone (since all the other possible dehydration products containing ketonic groups are known), was obtained (Found: C, 73·6; H, 6·6. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2%). Accompanying this derivative was another compound, m. p. 97—98°, identical with that obtained by dehydration of the glycol with concentrated sulphuric acid.

An attempt to isomerise *r*-*m*-tolyl α-phenylpropyl ketone similarly by the action of concentrated sulphuric acid failed, the ketone being recovered unchanged.

Constitution and Syntheses of the Dehydration Products.

(1) *Scission of Phenyl*-m-*tolylethylacetaldehyde*.—The aldehyde (5 g.) was boiled with potassium hydroxide (24 g. in 80 c.c. of ethyl alcohol) for 20 hours. The ethereal extract of the alkaline liquor yielded α-*phenyl*-α-m-*tolylpropane* as an oil, b. p. 143—144°/17 mm. (1·8 g., $n_{5893}^{16°}$ 1·5650) (Found: C, 91·9; H, 8·3. $C_{16}H_{18}$ requires C, 91·4; H, 8·6%). On acidification of the liquors and extraction with ether, the presence of formic acid was noted in the residue from the ethereal solution.

(2) *Attempted Scission of* r-m-*Tolyl-α-Phenylpropyl Ketone.*—The ketone (1 g.) was boiled for 10 hours with alcoholic potash (10 g. of potassium hydroxide in 35 c.c. of ethyl alcohol). Extraction of the alkaline liquor yielded 0·85 g. of unchanged ketone, and no acid was detected in the acid portion.

(3) *Synthesis of* r-m-*Tolyl α-Phenylpropyl Ketone.*—Phenylethylacetonitrile (Bodroux and Taboury, *Compt. rend.*, 1910, **150**, 531) (19 g., 1 mol.) was added in ethereal solution to the Grignard reagent prepared from *m*-bromotoluene (47 g., 4 mols.) and boiled for 4 hours. After decomposition with ice and concentrated hydrochloric acid and immediate separation of the acid and the ethereal layer, a solid (1 g.) separated from the former. After crystallisation from light petroleum, prisms, m. p. 82—83°, alone or mixed with the ketone of similar m. p. obtained by dehydrating the glycol with concentrated sulphuric acid, were obtained.

(4) *Synthesis of* r-*Phenyl*-m-*tolylmethyl Ethyl Ketone.*—Phenyl-*m*-tolylacetonitrile (10 g., 1 mol.) (Roger and McKay, J., 1933, 332) was added to the Grignard reagent prepared from ethyl bromide (27 g., 5 mols.) and boiled for 11 hours. The mixture was worked up as in (3), and from the acid layer, after 24 hours' standing, an oil (3·1 g.) was obtained. This did not solidify, but gave a *semicarbazone*, m. p. 161°, as hard incrusted masses from alcohol (Found: C, 73·4; H, 7·5. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2%), probably that of *r*-phenyl-*m*-tolylmethyl ethyl ketone.

(5) *Attempted Synthesis of* r-α-m-*Tolylbutyrophenone.*—*m*-Tolylethylcarbinol (25 g.) (Auwers and Kolligs, *Ber.*, 1922, **55**, 43) was converted by means of thionyl chloride into α-chloro-α-*m*-tolylpropane (13 g.), b. p. 104—106°/21 mm. (Found: Cl, 21·3. Calc. for $C_{10}H_{13}Cl$: Cl, 21·1%). Heating with mercuric cyanide in benzene solution did not give the required cyanide, but resulted in the scission of a molecule of hydrogen chloride and the formation of an unsaturated hydrocarbon, a colourless oil, b. p. 87—88°/25 mm., 194—197°/761 mm. (Found: C, 91·0; H, 9·2. $C_{10}H_{12}$ requires C, 90·9; H, 9·1), probably m-*propenyltoluene.* The synthesis of the ketone was thus unsuccessful.

r-2-*Phenyl*-1-o-*tolyl*-1-*ethylethylene Glycol* (*α-Form*).

Preparation.—Phenylpropionylcarbinol (17 g., 1 mol.) was added to the Grignard reagent prepared from *o*-bromotoluene (58 g., 3 mols.), and the mixture treated in the same manner as described for the *p*-isomer. The crude *solid* had m. p. 76—79°, and crystallised from light petroleum in hard nodules of needles, m. p. 80—81° (Found: C, 79·4; H, 8·1. $C_{17}H_{20}O_2$ requires C, 79·6; H, 7·9%).

Dehydration with Concentrated Sulphuric Acid.—The glycol (6 g.) was added in small amounts to concentrated sulphuric acid (20 c.c.) with stirring, and a claret coloration developed. After 19 hours, the mixture was poured into ice and water, and a solid separated (m. p. 36—40°, 2·8 g.). The filtrate was extracted with ether, and the extract yielded a small amount of the above solid. The combined solids were recrystallised twice from aqueous alcohol. r-o-*Tolyl α-phenylpropyl ketone* separated from aqueous alcohol in colourless rectangular plates, m. p. 39·5° (Found: C, 85·3; H, 7·3. $C_{17}H_{18}O$ requires C, 85·7; H, 7·6%). This ketone did not form either a semicarbazone or a 2 : 4-dinitrophenylhydrazone.

Dehydration with Dilute Sulphuric Acid.—The glycol (4 g.) was boiled with dilute sulphuric acid (25% by vol.) for 6·5 hours. The oil obtained had b. p. 165—175°/16 mm., $n_{5893}^{14°}$ 1·5936, and was converted into the *semicarbazone* of phenyl-*o*-tolylethylacetaldehyde, which separated from benzene as fine needles, m. p. 168—169° (Found: C, 73·1; H, 7·5. $C_{18}H_{21}ON_3$ requires C, 73·2; H, 7·2%).

Dehydration with Oxalic Acid.—The glycol (13 g.) was boiled with fused hydrated oxalic acid for 7 hours. The product was an oil, b. p. 176—178°/20 mm. (10 g., $n_{5893}^{12°}$ 1·5878), which yielded the semicarbazone of phenyl-*o*-tolylethylacetaldehyde, m. p. 168—169° (fine needles from benzene), alone or mixed with the foregoing semicarbazone.

Isomerisation of Phenyl-o-tolylethylacetaldehyde.—The aldehyde (4·6 g.) was triturated with concentrated sulphuric acid (15 c.c.) for 19 hours. A brown-red coloration developed, and the product was finally extracted in the usual manner. The solid was recrystallised from aqueous alcohol and separated as colourless, rectangular plates, m. p. 39—40°, alone or mixed with *r*-*o*-tolyl α-phenylpropyl ketone obtained by the dehydration of the glycol with concentrated sulphuric acid.

Constitution and Synthesis of the Dehydration Product.

Synthesis of r-o-*Tolyl α-Phenylpropyl Ketone.*—Phenylethylacetonitrile (11 g.) was added to the Grignard reagent prepared from *o*-bromotoluene (52 g., 4 mols.). After 4 hours' boiling, the product was worked up as in the analogous preparations, and the ethereal extract of the acid

layer yielded an oil (1·5 g.); when this was dissolved in aqueous alcohol, colourless, rectangular plates separated, m. p. 39—40°, alone or mixed with the ketone described in the preceding paragraph.

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368. *Acenaphthenone and Acenaphthenequinone.*

By H. GORDON RULE and SAMUEL B. THOMPSON.

The bromination of acenaphthenequinone is readily effected by boiling the quinone with excess of liquid bromine, 3-bromoacenaphthenequinone being formed in excellent yield. More vigorous bromination in the presence of iron yields a *tribromoacenaphthenequinone* of uncertain constitution.

An improved method for the preparation of acenaphthenone is the reduction of acenaphthenequinonephenylhydrazone by means of iron and acid. When treated with excess of bromine in carbon disulphide solution, acenaphthenone yields 7 : 7-dibromoacenaphthenone.

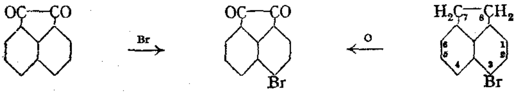
7 : 7-Dichloroacenaphthenone, when treated with hot aqueous sodium sulphide solution, is converted almost quantitatively into 7 : 7′-diacenaphthylidene-8 : 8′-dione. With sodium hyposulphite the latter undergoes further reduction to the colourless 7 : 7′-*diacenaphthenonyl*, the constitution of which has been confirmed by synthesis.

The characteristically wide range over which acenaphthenequinonemonoxime melts is shown to be due to molecular rearrangement into naphthalimide at the temperature of fusion.

ALTHOUGH acenaphthenequinone and acenaphthenone have been recognised as individuals for many years and have formed the subject of various important investigations, our knowledge of their chemistry is still far from complete. The constitutions of the dinitro-derivatives of the quinone have only recently been established with certainty (Rowe and Davies, J., 1920, **117**, 1349; Mayer and Kaufmann, *Ber.*, 1920, **53**, 296; Rule and Brown, J., 1934, 171) and up to the present the only bromoacenaphthenequinone described in the literature has been obtained indirectly by way of bromoacenaphthene. Further, no convenient method of preparing acenaphthenone has yet been recorded.

Bromoacenaphthenequinones.—Mayer and Kaufmann (*loc. cit.*, p. 289) stated that no uniform product could be isolated by the direct bromination of acenaphthenequinone, and Mayer and Schoenfelder (*Ber.*, 1922, **55**, 2972), using bromine in nitrobenzene solution at 200°, obtained only naphthalic anhydride.

Direct bromination has now been achieved by boiling a solution of acenaphthenequinone (6 g.) in bromine (10 c.c.) for 2 hours under reflux at 60—70°. The mixture was poured into water acidified with sulphuric acid, and the excess of bromine boiled off. Crystallisation of the resulting solid from acetic acid gave 3-bromoacenaphthenequinone, m. p. 231—233° (6·7 g.; 80% yield). Further recrystallisation gave the pure compound, m. p. 238°, unchanged on admixture with a specimen prepared by the oxidation of 3-bromoacenaphthene (Guha, J., 1931, 582, records m. p. 238°). Even under the most favourable conditions the oxidation process only led to a yield of about 10%.



3-Bromoacenaphthenequinone condensed with *o*-phenylenediamine to give the phenazine, m. p. 272° (Guha, *loc. cit.*, 272°; Dziewonski, Schoen, and Glazner, *Bull. Acad. Polonaise*,

1929, *A*, 636, find 261—263°). 3-*Bromoacenaphthenequinonemonoxime*, prepared from the quinone and hydroxylamine hydrochloride in aqueous alcohol, melted at 213—214·5° (Found: N, 5·0. $C_{12}H_6O_2NBr$ requires N, 5·1%).

No further bromination of 3-bromoacenaphthenequinone could be effected with bromine alone. A solution of the quinone (2 g.) in bromine (5 c.c.) was treated carefully with iron filings (1 g.) and the mixture, after being heated for 2 hours at 60—70°, was poured into water acidified with sulphuric acid and was boiled to expel the excess of bromine. Repeated crystallisation of the product from acetic acid afforded fine yellow needles of a *tribromoacenaphthenequinone* (1·2 g.), m. p. 253—256° (Found: Br, 57·7. $C_{12}H_3O_2Br_3$ requires Br, 57·3%); the somewhat wide range of fusion may be due to the presence of a trace of a tetrabromo-derivative. In all probability the tribromo-quinone contains the bromine atoms in the 2-, 3-, and 5-positions.

Treatment of the tribromo-quinone with *o*-phenylenediamine in boiling acetic acid afforded the *phenazine* of tribromoacenaphthenequinone, m. p. 303° (Found: N, 6·0. $C_{18}H_7N_2Br_3$ requires N, 5·7%).

Oxidation converted the quinone into a tribromonaphthalic anhydride, obtainable in better yield by direct bromination of naphthalic anhydride (see following paper).

Prolonged bromination in the presence of iron, followed by repeated crystallisation from acetic acid, gave a *tetrabromoacenaphthenequinone* (2 : 3 : 4 : 5-?) in fine needles, m. p. 300—305° (Found: Br, 64·7. $C_{12}H_2O_2Br_4$ requires Br, 64·3%), but owing to the small yield and the difficulty of purification this compound was not further investigated.

Acenaphthenone and its Derivatives.—The best method hitherto available for the preparation of acenaphthenone is that of Graebe and Jequier (*Annalen*, 1896, **290**, 195; Morgan and Stanley, *J. Soc. Chem. Ind.*, 1925, 493T) in which acenaphthenequinone is converted by treatment with phosphorus pentachloride into 7 : 7-dichloroacenaphthenone, and the latter then reduced with zinc and acetic acid ($CO{\cdot}CO \longrightarrow CO{\cdot}CCl_2 \longrightarrow CO{\cdot}CH_2$), the yield being about 30%.

A more convenient method (yield, 45%) is the following: Acenaphthenequinone (30 g.) in hot acetic acid (240 c.c.) was treated cautiously with phenylhydrazine (20 g.) in acetic acid (60 c.c.) and the red solution of the hydrazone was boiled for 5 minutes and treated with concentrated hydrochloric acid (100 c.c.); iron filings (40 g.) were then added in small portions to the boiling mixture.* After 1 hour at the b. p., the product was poured into water, and the acenaphthenone distilled in steam. Yield, 12·5 g.; m. p. 121°.

Another method, which has the merit of economy, is to convert acenaphthene (50 g.) into acenaphthenequinonemonoxime by treatment with amyl nitrite and hydrogen chloride (Reissert, *Ber.*, 1911, **44**, 1749) and to reduce the oxime as indicated above with iron in a mixture of acetic and hydrochloric acids. Yield, 14 g. (26%). The claim made by Reissert to have isolated an isomeric oxime, distinguished by a lower solubility in sodium carbonate solution than the one referred to above, could not be substantiated.

In this connexion the behaviour of acenaphthenequinonemonoxime in a melting point tube was examined. Fusion normally occurred over a range of 2—3° with apparent decomposition. The chemical change proceeded more rapidly at higher temperatures, and when the tube was immersed in a bath at 250° a crystalline sublimate of naphthalimide, m. p. and mixed m. p. 298°, deposited on the upper part of the tube. The molecular rearrangement thus represents a Beckmann transformation under the influence of heat alone.

Another method of preparing acenaphthenone is the reduction of the quinone monoanil: this was obtained by Sander (*Ber.*, 1925, **58**, 830) by the interaction of acenaphthenone and nitrosobenzene, but it is more readily prepared by heating acenaphthenequinone and aniline in the required proportion for a few minutes at 130°.

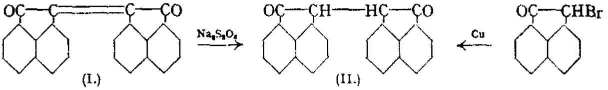
In agreement with the conclusions of earlier workers, the direct bromination of acenaphthenone was found to occur only in the side chain; the reaction, however, may proceed a stage further than the monobromo-compound obtained by Graebe and Jequier (*loc. cit.*). 7 : 7-Dibromoacenaphthenone was prepared by carefully treating a solution of acenaphthenone (2 g.) in carbon disulphide (15 c.c.) with a solution of bromine (2 c.c.) in the same solvent and after a short time boiling the mixture until no more hydrogen bromide was evolved. The dibromoacenaphthenone obtained on evaporation of the solvent formed colourless crystals,

* The authors wish to thank Mr. G. M. Henderson, B.Sc., for assistance in improving this preparation.

m. p. 161—162°, from ether (Behrend and Herms, *J. pr. Chem.*, 1899, **60**, 1, record m. p. 160—161° for the compound prepared indirectly by way of the hydrazide and the azide).

Dinuclear Condensation Products.—7 : 7'-Diacenaphthylidene-8 : 8'-dione (I) has been isolated in small yields by Graebe by several methods (*Annalen*, 1893, **276**, 1; 1896, **290**, 201); its preparation as a vat dye has also been claimed by the condensation of acenaphthenequinone with acenaphthenone (D.R.-P. 212, 858; *Cent.*, 1909, II, 775). It has now been obtained very readily and in almost quantitative yield as follows:

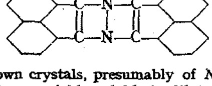
7 : 7-Dichloroacenaphthenone (10 g.) in alcohol (200 c.c.) was reduced with sodium sulphide (12 g. of $Na_2S,9H_2O$ in 50 c.c. of water). Rapid addition of the reagent led to a vigorous reaction and deposition of the flocculent red dione (yield, 6·5 g.; 93% of the theoretical). Purified from nitrobenzene, it melted at 300°.

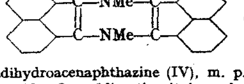


(I.) (II.)

The orange diacenaphthylidenedione did not possess the properties of a vat dye. When the compound (2 g.) was heated at 100° with an alkaline solution of sodium hyposulphite, it was converted into a colourless reduction product which did not undergo reoxidation in air. After crystallisation from nitrobenzene the product (1·9 g.) melted at 258° (Found: C, 86·1; H, 4·1. $C_{24}H_{14}O_2$ requires C, 86·2; H, 4·2%). It could not be acetylated and is therefore concluded to be non-hydroxylic and is assigned the ketonic structure 7 : *7'-diacenaphthenonyl* (II) to which the enolic compound first produced by reduction of the ketonic groups of the dione is assumed to isomerise. This constitution is supported by the formation of the same compound when 7-bromoacenaphthenone (1·2 g.) was boiled in xylene (10 c.c.) for 1 hour with copper bronze (0·6 g.). On filtration and cooling, fine colourless crystals (0·2 g.; 25% of the theoretical yield) were obtained, m. p. after crystallisation from acetic acid 258°, alone or mixed with the above product. Diacenaphthenonyl was also obtained by reduction of diacenaphthylidenedione with zinc dust (or iron filings) and acetic acid. While investigating the formation of the dione from acenaphthenequinone by heating with hydriodic acid and red phosphorus at 120°, Graebe records failure to obtain products other than the dione in this manner. When the temperature of the reaction is raised to 165°, however, the product is no longer Graebe's dione but the above diacenaphthenonyl (yield, 44%).

A red dinuclear condensation product of a different type was isolated by the action of ammonia upon 7 : 7-dichloroacenaphthenone. This proved to be identical with the compound obtained by Graebe by interaction of ammonia and acenaphthenequinone (*Annalen*, 1893, **276**, 9) and later formulated by Schönberg (*Ber.*, 1921, **54**, 238) as acenaphthazine (*III*). When the quinone (4·5 g.) was heated with aqueous methylamine (3 c.c. of 30% wt./vol.) in a sealed tube for 6 hours at 100°, a black mass was formed, which, on being washed with acetone and chloroform, left a brown amorphous residue. Crystallisation from nitrobenzene afforded large,

(III.) 



(IV.)

dark brown crystals, presumably of *NN'*-dimethyldihydroacenaphthazine (IV), m. p. above 360°, not appreciably soluble in dilute hydrochloric acid. On sublimation it formed reddish-brown needles (Found: N, 8·0. $C_{26}H_{18}N_2$ requires N, 7·8%).

The authors acknowledge their indebtedness to the Carnegie Trustees for the award of a Research Scholarship (to S. B. T.) and a Teaching Fellowship (to H. G. R.)

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369. *Bromo- and Nitro-derivatives of Naphthalic Acid.*

By H. Gordon Rule and Samuel B. Thompson.

The bromination of naphthalic anhydride in a mixture of oleum and sulphuric acid leads, not to 4-bromonaphthalic anhydride as stated by Francesconi and Bargellini, but to *3-bromonaphthalic anhydride*, m. p. 244°. This compound may also be prepared by bromination in nitric acid solution, or less satisfactorily by heating the anhydride with bromine in a sealed tube. Bromination in an alkaline medium, on the other hand, gives 4-bromonaphthalic anhydride, m. p. 222°. In the presence of iron filings, naphthalic anhydride may be brominated to a *tribromonaphthalic anhydride*, m. p. 232°, probably the 3 : 4 : 6 (or the 3 : 4 : 5)-compound.

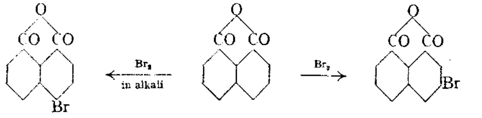
Homonuclear substitution occurs when 4-bromonaphthalic anhydride is nitrated, with formation of *4-bromo-3-nitronaphthalic anhydride*. Further nitration of 4-nitronaphthalic anhydride, however, affords 4 : 5-dinitronaphthalic anhydride as the main product.

The mercuration of 3-bromonaphthalic anhydride, followed by hydrolysis with mineral acid, gives a mixture of bromo-acids from which *3-bromo-1-naphthoic acid*, m. p. 231—232°, can be isolated. In a similar manner 5-bromo-1-naphthoic acid is obtained from the 4-bromo-anhydride.

The only record of the direct bromination of naphthalic anhydride is by Francesconi and Bargellini (*Gazzetta*, 1902, **32**, 87), who prepared a number of halogeno- and nitro-derivatives; in all cases halogenation was carried out in a mixture of oleum and sulphuric acid, the use of bromine giving a product which could only be purified with difficulty and was assumed to be identical with 4-bromonaphthalic anhydride obtained by oxidation of 3-bromoacenaphthene.

During the present investigation naphthalic anhydride was first brominated by heating the reactants for a considerable time in a sealed tube, and a monobromo-compound, m. p. 244°, was isolated which differed from 4-bromonaphthalic anhydride and was shown to be *3-bromonaphthalic anhydride* by its synthesis from 3-nitronaphthalic anhydride. Subsequent repetition of the bromination in oleum and sulphuric acid as described by Francesconi and Bargellini also led to the 3-bromo-compound. Owing to the troublesome experimental procedure and low yields, neither of these methods is satisfactory. Better results are obtained by carrying out the bromination in nitric acid solution: although the yield (20%) is still somewhat low, the preparation is rapidly effected and under the correct conditions (see experimental section) the product crystallises from the reaction mixture in the pure state.

When the bromination was carried out in an alkaline medium in presence of sodium hypobromite, 4-bromonaphthalic anhydride, m. p. 222°, was obtained in good yield.



Under more vigorous conditions, bromine and iron filings being used, a *tribromonaphthalic anhydride* was produced. As dinitration of the anhydride is known to lead to the formation of the symmetrical 3 : 6-dinitro-derivative (Rule and Brown, J., 1934, 171) and disulphonation has been found to take the same course (Rule and Douglas, unpublished work), it appears probable that the tribromo-compound contains bromine in the 3 : 4 : 6- or less likely in the 3 : 4 : 5-positions. The same compound may be obtained from acenaphthenequinone or its 3-bromo-derivative on bromination in the presence of iron, followed by oxidation (see preceding paper), but the yield by this method is smaller owing to the difficulty of removing other products which are formed during the bromination.

The nitration of 4-bromonaphthalic anhydride led somewhat unexpectedly to homonuclear substitution and the formation of *4-bromo-3-nitronaphthalic anhydride*, the structure of which was proved by synthesis from 2-nitro-3-aminoacenaphthene. On the other hand, 4-nitronaphthalic anhydride on further nitration gave rise to the 4 : 5-dinitro-derivative.

One of the difficulties encountered in working with the naphthalic anhydride group lies in the often considerable discrepancies in the melting points of these compounds recorded in the literature. For the better characterisation of the compounds under discussion a number of their more important derivatives have been prepared. Symmetrically substituted anhydrides are conveniently identified by conversion into the 1′ : 8′-naphthoylene-1 : 2-benziminazoles formed by union with *o*-phenylenediamine. Derivatives of this type have been prepared by Chakravarti (*J. Indian Chem. Soc.*, 1924, **1**, 19) and Bistrzycki and Risi (*Helv. Chim. Acta*, 1925, **8**, 810), who obtained them by heating the reactants together at a high temperature. It has now been found that a simpler method is to effect the condensation in boiling acetic acid solution. When heated with nitrobenzene as solvent, the starting materials were recovered largely unchanged.

The mercuration of 3-bromonaphthalic anhydride gave rise to a mixture of anhydromercuri-naphthoic acids, from which no pure dibromonaphthoic acid could be prepared by treatment with bromine. From the mixture of bromonaphthoic acids formed on boiling the mercurated compound with hydrochloric acid, a small yield (23%) of *3-bromo-1-naphthoic acid* was isolated, this structure being proved by the synthesis of the compound from 3-nitro-1-naphthoic acid. In a similar manner the mercuration of 4-bromonaphthalic anhydride led to the production of a mixture of naphthoic acids, from which 5-bromo-1-naphthoic acid was separated by fractional crystallisation.

Experimental.

Naphthalic anhydride, m. p. 272—273°, forms a benziminazole derivative, m. p. 206°, which is pale yellow, and remains unchanged after 2 hours' heating at 215° (Chakravarti and Bistrzycki and Risi, *locc. cit.*, give m. p. 198° and 189° respectively).

Bromination of Naphthalic Anhydride.—(a) The anhydride (5 g.) was heated with bromine (2 c.c.) for 18 hours at 150°. After extraction of unchanged material with hot alcohol (75 c.c.), a second extraction removed *3-bromonaphthalic anhydride*, m. p. 244° after recrystallisation from alcohol or sublimation (Found : C, 52·0; H, 1·8; Br, 29·0. $C_{12}H_5O_3Br$ requires C, 51·9; H, 1·9; Br, 28·9%); mixed m. p. with the 4-bromo-derivative (m. p. 222°) 190—200°.

(b) Naphthalic anhydride (20 g.) was brominated in a mixture of oleum and sulphuric acid as described by Francesconi and Bargellini (*loc. cit.*), giving a product which on crystallisation from acetic anhydride melted at 238—241° (yield, 6·3 g.; 25%), not depressed by admixture with the above compound, m. p. 244° (F. and B. record m. p. 211—212° for their purest product and state no yield).

(c) Naphthalic anhydride (5 g.) was dissolved in concentrated nitric acid (100 c.c.) by rapid heating to 70°. Bromine (3 g.) was added, the temperature being maintained at 60—70°, and after ½ hour the mixture was cooled in water and kept overnight; fine colourless needles (1·4 g.; 20%) of 3-bromonaphthalic anhydride crystallised, m. p. 242—243°. When the acid filtrate was poured into water, less than 1 g. of solid separated, from which a further small amount of the bromo-anhydride was isolated by recrystallisation.

3-Nitronaphthalic anhydride was converted through the amino- into the bromo-derivative, which sublimed in colourless needles, m. p. 244° alone or mixed with the above-mentioned specimens.

3-Bromonaphthalimide, prepared from the anhydride and concentrated aqueous ammonia, melted at 316° (Found : N, 4·95. $C_{12}H_6O_2NBr$ requires N, 5·1%). *Methyl 3-bromonaphthalate* was prepared by use of methyl sulphate and 10% aqueous sodium carbonate; crystallised from alcohol, it melted at 105° (Found: Br, 25·1. $C_{14}H_{11}O_4Br$ requires Br, 24·8%). *3-Bromonaphthalophenylhydrazide*, crystallised from acetic acid, melted at 223—224°. This m. p. was recorded by Francesconi and Bargellini (*loc. cit.*) for the phenylhydrazide prepared from a crude bromo-anhydride incorrectly assumed to be the 4-bromo-compound.

(d) A solution of naphthalic anhydride (20 g.) in hot aqueous potassium hydroxide (28 g. in 120 c.c.) was cooled in ice and treated with bromine (48 g., added during 2½ hours). The temperature was then raised to 60° and maintained for 24 hours, an excess of sulphuric acid

added, and the mixture boiled for a short time. The 4-bromonaphthalic acid obtained was recrystallised from nitrobenzene; yield, 12 g. (43%); m. p. 214—216°. The pure anhydride melts at 222°. Melting points observed for the methyl ester and the imide were in agreement with those already recorded by Dziewonski and Koewa (*Bull. Acad. Polonaise*, 1928, *A*, 405), but the phenylhydrazide was found to melt at 231° (Dziewonski records 223—224°). A mixed m. p. of the phenylhydrazides prepared from the 3- and the 4-bromonaphthalic anhydride showed strong depression.

(e) Iron filings (2 g.) were added to a suspension of naphthalic anhydride (10 g.) in bromine (20 c.c.), the mixture being then boiled under reflux for 15 hours. The product was poured into water (1 l.) acidified with sulphuric acid, and the excess of bromine boiled off. Filtration gave a solid, which was extracted with a boiling solution of sodium carbonate. The filtered extract deposited on cooling the sodium salt of the tribromo-acid, sodium chloride being added to make the separation more complete. After crystallisation from water (lustrous plates, 18 g.), treatment with acid and crystallisation from acetic anhydride afforded *tribromonaphthalic anhydride*, m. p. 232°. Yield, 13 g. (60%) (Found: Br, 54·9. $C_{12}H_3O_3Br_3$ requires Br, 55·1%).

Nitration of 4-Bromonaphthalic Anhydride.—The anhydride (3 g.), dissolved in sulphuric acid (20 c.c.), was treated gradually at 15—20° with a mixture of nitric acid (0·5 c.c., *d* 1·51) and sulphuric acid (10 c.c.), and the whole heated for 1 hour at 100°. The product was precipitated with water and crystallised from acetic anhydride. Yield, 1·4 g. (40%); m. p. 229—230°. Further crystallisation from nitric acid gave colourless needles of *4-bromo-3-nitronaphthalic anhydride*, m. p. 231—232° (Found: N, 4·5. $C_{12}H_4O_5NBr$ requires N, 4·35%). The orientation of the nitro-group was proved by the following synthesis: 2-nitro-3-aminoacenaphthene (Morgan and co-workers, *J. Soc. Chem. Ind.*, 1924, 343 T; 1925, 493 T; 1930, 413 T) (5 g.) was dissolved in 85% sulphuric acid (40 c.c.) and glacial acetic acid (50 c.c.), sodium nitrite (3·5 g.) and ice (200 g.) added, and the diazo-solution poured into a solution of cuprous bromide (10 g.) in 20% hydrobromic acid. The temperature was slowly raised to 60°, and the mixture kept overnight. The solid deposit (6 g.) was filtered off and extracted with light petroleum, the extract yielding orange crystals, m. p. 130—135° (2·5 g.). Further crystallisation from light petroleum afforded long rectangular prisms of *3-bromo-2-nitroacenaphthene*, m. p. 143° (Found: Br, 29·1. $C_{12}H_8O_2NBr$ requires Br, 28·8%). Sodium dichromate (10 g.) was gradually added to a solution of 3-bromo-2-nitroacenaphthene (2 g.) in glacial acetic acid (25 c.c.) at 70—80°. After further heating for 30 minutes on a water-bath the mixture was poured into water acidified with sulphuric acid and the anhydride was extracted from the precipitated solid with aqueous sodium carbonate. After recrystallisation from nitric acid fine colourless needles of 4-bromo-3-nitronaphthalic anhydride (0·4 g.) were obtained, m. p. 232° alone or mixed with the product obtained by nitrating 4-bromonaphthalic anhydride.

Nitration of 4-Nitronaphthalic Anhydride.—The anhydride (5 g.) was treated with concentrated sulphuric acid (30 c.c.) and sodium nitrate (2 g.), and the temperature slowly raised to 100°. Crystals of 4 : 5-dinitronaphthalic anhydride soon began to separate and after 15 minutes the pasty mass was allowed to cool. Yield, 2·2 g.; m. p. 320—322°, raised to 323—325° on crystallisation from nitric acid. The m. p. of a specimen of 4 : 5-dinitronaphthalic anhydride prepared from acenaphthenequinone (Rowe and Davies, J., 1920, **117**, 1344; Mayer and Kaufmann, *Ber.*, 1920, **53**, 289) rose to 327—329° after several recrystallisations from nitric acid (Mayer and Kaufmann record m. p. about 310°, not sharp). Mixed with the above nitro-compound, this substance melted at 326—328° and each sample under the microscope showed the same crystalline form of elongated rectangular plates.

Condensation of Naphthalic Anhydride with o-*Phenylenediamine.*—The anhydride (2 g.), dissolved in boiling acetic acid (60 c.c.), was treated with *o*-phenylenediamine (1·2 g.) in acetic acid (10 c.c.). After being boiled for ½ hour, the liquid on cooling deposited fine yellow crystals of 1′ : 8′-naphthoylene-1 : 2-benziminazole, which were washed with a little cold acetic acid. Yield, 2·2 g.; m. p. 204—205°, raised to 206° on recrystallisation from chlorobenzene (Found: N, 10·3. Calc. for $C_{18}H_{10}ON_2$: N, 10·4%). *4′ : 5′-Dinitro-1′ : 8′-naphthoylene-1 : 2-benziminazole*, obtained in a similar manner from 4 : 5-dinitronaphthalic anhydride, separated in fine bronze needles, m. p. 370° (Found: N, 15·5. $C_{18}H_8O_5N_4$ requires N, 15·55%).

3 : 6-Dinitronaphthalic acid was prepared by the method of Francesconi and Bargellini (*loc. cit.*; see also Rule and Brown, J., 1934, 173). It was observed that the acid, m. p. 210°, deposited unchanged after being boiled with nitrobenzene. In this respect it differs from naphthalic acid, which undergoes conversion into the anhydride. Francesconi and Bargellini state that the anhydride, m. p. 266° (decomp.), may be obtained by crystallising the dinitro-

acid from nitric acid. During the present work a sample of 3 : 6-dinitronaphthalic acid which had been purified from nitrobenzene was recrystallised from nitric acid, giving long colourless needles, m. p. 330°, without any sign of decomposition (Found : N, 10·0. Calc. for $C_{12}H_6O_8N_2$: N, 9·7%). Condensation with *o*-phenylenediamine afforded 3′ : 6′-*dinitro*-1′ : 8′-*naphthoylene*-1 : 2-*benziminazole* in orange crystals, m. p. 301° (Found : N, 15·2. $C_{18}H_8O_4N_4$ requires N, 15·55%).

Mercuration of Substituted Naphthalic Anhydrides.—This was effected by the method of Whitmore and Fox (*J. Amer. Chem. Soc.*, 1929, **51**, 3363). The mercuration product from 4-bromonaphthalic anhydride (10 g.), when boiled for 3 hours with 5N-hydrochloric acid, gave an almost quantitative yield of bromonaphthoic acids, from which, on crystallisation from acetic acid, 2 g. (35%) of 5-bromo-1-naphthoic acid were isolated, m. p. 256—258°, not depressed by the product (m. p. 260°) obtained by the direct bromination of naphthoic acid.

The mercuration of 3-bromonaphthalic anhydride (8·3 g.), followed by hydrolysis with mineral acid, gave a mixture of bromonaphthoic acids (6·7 g.), from which, after four recrystallisations from acetic acid, 3-*bromo*-1-*naphthoic acid* (1·6 g., 23%) was isolated, m. p. 231—232°, not changed by sublimation. The position of the bromine atom was proved by synthesis, 3-nitronaphthalic acid being mercurated and the product hydrolysed to give a mixture from which 3-nitro-1-naphthoic acid was obtained (cf. Leuck, Perkins, and Whitmore, *J. Amer. Chem. Soc.*, 1929, **51**, 1833). The last-named acid (2 g.) was reduced with sodium hyposulphite and the amino-acid, without being isolated, was diazotised and treated with cuprous bromide in hydrobromic acid. The crude 3-bromonaphthoic acid was mixed with graphite (4 parts) and sublimed, giving 0·3 g., m. p. 237—238° alone or when mixed with the above specimen, m. p. 234—236° (Found : C, 52·2; H, 2·9; Br, 31·4. $C_{11}H_7O_2Br$ requires C, 52·6; H, 2·8; Br, 31·8%). More conclusive proof of identity was obtained by converting each sample of bromo-acid into *methyl* 3-*bromo*-1-*naphthoate* by the thionyl chloride method; after crystallisation from aqueous alcohol the products melted at 59° alone or mixed (Found : Br, 30·6. $C_{12}H_9O_2Br$ requires Br, 30·2%).

The mercuration of the above-mentioned tribromonaphthalic anhydride was also effected, but hydrolysis led to a mixture of tribromonaphthoic acids which could not be separated. In none of the above cases could any definite compounds be isolated by brominating the mercury compounds.

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University of Edinburgh. [*Received, June 25th*, 1937.]

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370. *The Course of Hydrogenation in Mixtures of Mixed Glycerides.*

By W. J. Bushell and T. P. Hilditch.

When natural fats consisting largely of mixtures of palmito-di-unsaturated glycerides and tri-unsaturated glycerides (oleolinoleins, etc.), such as cottonseed oil or pig depot fat, are hydrogenated, the first-mentioned group pass into palmitostearins to a very large degree before any tristearin is produced. In order to ascertain the cause of this apparent selective action, binary mixtures of suitable mixed triglycerides of known structure and configuration have been hydrogenated until approximately half of the products consisted of fully-saturated glycerides, the composition (tristearin content) of the latter being then determined. It has been shown that the composition of the hydrogenated fats is the resultant of a number of factors, notably (i) the relative rates of the step-wise hydrogenation of tri-, di- and mono-unsaturated triglycerides and (ii) the proportion of each of these three types present in the original fat. The present results also show that the tentative hypothesis, previously put forward, that the observed preferential production of β-palmitodistearin during hydrogenation of a number of natural fats (including those mentioned above) may be due to relative difficulty of hydrogenation of β-oleoglycerides, is incorrect.

Natural fats are mixtures of mixed triglycerides, in which none, one, two or all of the acyl groups present may be unsaturated. Cottonseed oil, for instance, is made up ap-

proximately of about 25% of tri-unsaturated glycerides (oleolinoleins) and nearly 75% of monopalmito-di-unsaturated glycerides, with very small amounts of dipalmito-glycerides. Having examined olive and cottonseed oils hydrogenated to varying extents, Hilditch and Jones (J., 1932, 805) showed that, after the initial selective conversion of linoleic into mono-ethenoid radicals, the action proceeds in the stages triolein ⟶ di-oleo-mono-saturated ⟶ mono-oleo-disaturated ⟶ trisaturated glycerides. The tri-unsaturated glycerides are attacked more rapidly than di-oleo-glycerides, and the latter somewhat more so than the mono-oleo-compounds. Hilditch and Jones also showed that, in both olive and cottonseed oils, the palmito-glycerides present were converted into the fully-saturated state before any appreciable quantity of tristearin was formed. Subsequently Hilditch and Stainsby (*Biochem. J.*, 1935, **29**, 90) observed similar marked preferential formation of palmito-distearin over tristearin during the progressive hydrogenation of pig depot fat, and also that the product was β-palmitodistearin. This led to the suggestion that the preferential production of fully-saturated (β-) palmito-glycerides might be due to relative ease of hydrogenation of oleic radicals attached to the α-glyceryl hydroxyl groups as compared with those attached in the β-position.

In order to test this hypothesis, a number of mono-oleo-disaturated glycerides have been prepared synthetically, or by separation from appropriate fats, and binary mixtures containing equal amounts of, for example, an oleodistearin and an oleodipalmitin have been hydrogenated half-way to complete saturation. Determination of the tristearin content of the product indicates the extent to which preferential formation of palmito-stearins occurred. Actually it has been found that the result is the same irrespective of whether the oleic group is attached to the α- or the β-glyceryl hydroxyl radical, and that, apart from a relatively slight tendency towards production of somewhat more palmito-stearin than tristearin, hydrogenation proceeds indiscriminately in all the instances studied. The idea that the position of the oleic group in the glyceride molecule affects the ease with which it undergoes hydrogenation was thus proved incorrect. Further attempts were therefore made to ascertain the reason for the marked preferential formation of fully-saturated palmito-glycerides during hydrogenation of the afore-mentioned natural fats. Instead of binary mixtures of equal amounts of two mono-oleo-glycerides, those in which the components were respectively mono- and di-oleo-, mono- and tri-oleo-, or di- and tri-oleo-glycerides were hydrogenated to a point at which the mixture should contain approximately 50% of fully-saturated and 50% of mono-oleo-glycerides. In these cases the originally less unsaturated component (*e.g.*, mono-oleo- in a mixture of mono-oleo-disaturated and di-oleo-monosaturated glycerides) consistently yielded the larger proportion of fully-saturated material, but there was usually 30—40% present of fully-saturated glycerides corresponding to the more unsaturated component. Results duplicating those obtained in the natural fats were, however, obtained when the proportion of the less-unsaturated component was increased to 75% of the binary mixture (the proportions of palmito-unsaturated glycerides in cottonseed oil and in pig fat are of the respective orders of 75% and 80%).

The preferential formation of fully-saturated palmito-glycerides over tristearin during hydrogenation of fats such as cottonseed oil or pig depot fat is therefore the resultant of several factors, the chief of which are the relative rates of step-wise hydrogenation of tri-, di- and mono-unsaturated triglycerides and the proportion of each of these three types present in the original fat. There is some evidence that, apart from these considerations, the presence of palmitic groups in the triglycerides favours in some slight measure hydrogenation of oleic groups; the possibility that chain-length of the saturated radicals in a mixed glyceride may have a subordinate effect on the hydrogenation of unsaturated groups also present remains to receive further investigation.

The method used was to hydrogenate each mixture of glycerides (using nickel–kieselguhr catalyst at 180° in an agitation apparatus) to approximately half-way between the stage of mono-oleo-disaturated glycerides and complete saturation (*i.e.*, to an iodine value of about 15). The products were oxidised with permanganate in acetone (Hilditch and Lea, J., 1927, 3106) in order to isolate the fully-saturated glycerides, which were then fractionally crystallised from ether in order to determine the amount of tristearin, etc., present

(Hilditch and Jones, *J. Soc. Chem. Ind.*, 1934, **53**, 13T). The minimum quantity of each binary mixture requisite for this sequence of operations was 50 g. It was clearly out of the question to prepare the large quantities of mixed glycerides necessary by the methods which have been employed by other investigators for the synthesis of individual mixed glycerides of known configuration. We have made use of the synthesis of α-monoglycerides (Hilditch and Rigg, J., 1935, 1774) whereby products containing about 90% of α-monoglyceride and 10% of αα′-diglyceride are obtained; further esterification of these compounds with a second fatty acid leads to the formation of triglycerides, about 93—95% of which consist of the α-mono-derivative of the first acid in combination with two radicals of the second acid. This order of purity was considered sufficient for the purpose of the present work. In one or two cases, mono-oleo-disaturated glycerides isolated from natural fats, or semi-hydrogenated products from synthesised palmitodiolein or stearodiolein, were employed. Although simplified methods of synthesis were thus used, the preparation of the requisite materials for hydrogenation occupied a very large proportion of the time devoted to the whole investigation. The materials which finally served as components of the various binary mixtures are summarised below (for further details see Experimental):—

	Approximate degree of purity, %.
Mono-oleo-disaturated glycerides.	
α-Oleodipalmitin (synthesised)	93
α-Oleodistearin (synthesised)	95
β-Oleodistearin (from *Allanblackia* fat)	96—97
β-Oleodistearin (from *Pentadesma* fat)	85 (15% oleopalmitostearin)
Oleodistearin (iod. val. 29·1, isolated from partly hydrogenated triolein, p. 1773)	91 (9% tristearin)
Di-oleo-monosaturated glycerides.	
α-Palmitodiolein (synthesised)	90—95
α-Stearodiolein (synthesised)	90
Tri-unsaturated glycerides.	
Triolein (synthesised)	100

Semi-hydrogenation of Mixtures of α- and β-Mono-oleodisaturated Glycerides.—α-Oleodipalmitin was mixed in equal proportions with each of four varieties of oleodistearin, and hydrogenated until the iodine value of the product was about 15, and the content of fully-saturated glycerides was in the region of 50%. The contents of tristearin in the fully-saturated glycerides were as follows, the figures in parentheses indicating the proportion of tristearin which would be expected if hydrogenation of α-oleo-glycerides were completely preferential:—

α-Oleodipalmitin + equal weight of	% Tristearin in fully-saturated glycerides.
α-oleodistearin (synthesised)	34 (50)
oleodistearin (iod. val. 29·1, isolated from partly-hydrogenated triolein, p. 1773)	37 (0)
β-oleodistearin (from *Allanblackia* fat)	69 (0)
β-oleodistearin (from *Pentadesma* fat)	43 (0)

With one exception, the percentage of tristearin is in the region of 40%, irrespective of the configuration of the oleodistearin in the mixtures. Other experiments were carried out with mixtures in which the palmitic derivative was, to a large extent, in the form of oleopalmitostearin. In one instance, a concentrate of oleopalmitostearin was prepared by crystallising pig depot fat from acetone, the material finally obtained containing about 63% of oleopalmitostearin together with 12% of fully-saturated palmitostearins and 25% of palmitodiolein. Semi-hydrogenation of a mixture of equal parts of this with β-oleodistearin (from *Allanblackia* fat) gave a product in which 47% of the fully-saturated glycerides consisted of tristearin. Palmitodiolein, hydrogenated to an iodine value corresponding with that of oleopalmitostearin, was similarly used as a source of the latter; but, as described later, the composition of the material was approximately 53% oleopalmitostearin, 24% palmitodiolein and 23% palmitostearins. Semi-hydrogenation of a mixture of equal parts of this material with β-oleodistearin (from *Allanblackia* fat) also gave a product, the fully-saturated components of which contained 47% of tristearin.

The above figures are in complete opposition to the view that glyceryl β-oleo-derivatives

are less readily hydrogenated than α-oleo-glycerides, and also display no marked evidence for the preferential formation of saturated palmito-glycerides.

Partial Hydrogenation of Triolein, α-Stearodiolein, and α-Palmitodiolein.—Further evidence that α- and β-oleo-glycerides are hydrogenated more or less indiscriminately, and that the hydrogenation in each of the three stages tri-oleo ⟶ di-oleo ⟶ mono-oleo ⟶ saturated glycerides is not wholly consecutive or "selective," was obtained by study of the partial hydrogenation of some individual unsaturated glycerides.

Triolein (synthesised) was hydrogenated to an iodine value of 32, *i.e.*, somewhat above that of oleodistearin (28·6); the composition of the product was found to be 15% tristearin, 57% oleodistearin and 28% dioleostearin. When hydrogenated further to iodine value 21, it still contained 5% dioleostearin, with 64% oleodistearin and 31% tristearin. Although, therefore, the amount of oleodistearin is substantial in the later stages of hydrogenation, some of it passes into tristearin concurrently with the completion of hydrogenation of dioleostearin to oleodistearin.

α-Stearodiolein (synthesised), hydrogenated to iodine value 13·5, contained 53% tristearin and 47% oleodistearin. The purest fractions of oleodistearin isolated from this product, and also from the above partly-hydrogenated trioleins, were each oxidised with potassium permanganate in acetone; the mono-azelaodistearin isolated from the acidic products of oxidation (Hilditch and Saletore, *J. Soc. Chem. Ind.*, 1933, **52**, 101T), after crystallisation from acetone and from light petroleum, melted finally in each case at 54—55°. β-Azelaodistearin, from the β-oleodistearin of *Allanblackia* fat, melts at 63° (Hilditch and Saletore, *loc. cit.*), whilst the azelaodistearin prepared from our synthesised α-oleodistearin melted at 50·5°. The melting points (54—55°) of the azelaodistearins obtained from partly-hydrogenated triolein or stearodiolein thus point to a mixture of both α- and β-azelao-derivatives, *i.e.*, α- and β-oleo-groups are hydrogenated with more or less equal facility.

α-Palmitodiolein (synthesised), hydrogenated to an iodine value of 30·7 (oleopalmitostearin, iod. val. 30·5), was similarly found to contain 23% of fully-saturated glycerides (palmitostearins), from which it follows that 53% of oleopalmitostearin and 24% of unchanged palmitodiolein were also present.

Partial Hydrogenation of Binary Mixtures of Glycerides containing Different Numbers of Unsaturated Acyl Groups.—Binary mixtures of equal quantities of mono-oleo- and di-oleo-, mono-oleo- and tri-oleo-, or di-oleo- and tri-oleo-glycerides were next studied, hydrogenation being, as before, continued until the iodine value of the product (*ca.* 15) indicated a stage midway between mono-oleo-disaturated glyceride and complete saturation. The approximate composition of the fully-saturated glycerides in the various hydrogenated products is given below, the ***left-hand column*** of figures referring in each case to the saturated product derived from the component of the original mixture which contained the ***smaller*** number of unsaturated acyl groups :—

	Fully-saturated components of hydrogenated product, %.	
50% of Mono-oleo- with 50% of di-oleo-glycerides.		
α-Oleodipalmitin and α-palmitodiolein	56 (stearodipalmitin)	44 (palmitodistearin)
α-Oleodipalmitin and α-stearodiolein	63 (stearodipalmitin)	37 (tristearin)
α-Oleodistearin and α-palmitodiolein	62 (tristearin)	38 (palmitodistearin)
Oleopalmitostearin * and α-stearodiolein	77 (palmitodistearin)	23 (tristearin)
50% of Mono-oleo-glyceride with 50% of triolein.		
α-Oleodipalmitin and triolein	61 (stearodipalmitin)	39 (tristearin)
50% of Di-oleo-glyceride with 50% of triolein.		
α-Palmitodiolein and triolein	59 (palmitodistearin)	41 (tristearin)

* Hydrogenated palmitodiolein (iod. val. 30·7).

These figures are much more consistent than those for the various mixtures of mono-oleo-glycerides (p. 1769), in that in each case the component which originally possessed a smaller number of unsaturated acyl groups has furnished the greater part of the completely saturated glycerides in the partly-hydrogenated products. We may, indeed, say that, in the main, the more unsaturated component of the mixture is attacked first, and is hydrogenated until both the components reach the same degree of unsaturation, after which hydrogenation of each proceeds simultaneously and indiscriminately. This is, however,

only a partial statement of what occurs, and must be supplemented by the following: hydrogenation of a less unsaturated (*e.g.*, mono-oleo-) component proceeds to some extent whilst the more unsaturated components (*i.e.*, tri- or di-oleo-) are still being reduced to that stage.

That this is the case is shown by separate experiments in which we hydrogenated equimolecular mixtures of (*a*) α-oleodipalmitin and triolein and (*b*) α-palmitodiolein and triolein to iodine values of 25 and 29 respectively (*i.e.*, degrees of unsaturation corresponding approximately with that of mono-oleo-disaturated glycerides alone). The fully-saturated glyceride contents of the products were respectively 17% and 14%, but no tristearin was present in either. This implies that, by the time the average unsaturation of the mixture was reduced to that of mono-oleo-disaturated glycerides, 25—30% of the less saturated components of the original mixture (but none of the triolein) had been transformed into completely saturated glycerides.

Put in other words, all unsaturated components in a mixture of glycerides are attacked concurrently during hydrogenation, but reduction of the more unsaturated components is relatively more rapid; this holds until the unsaturation of the mixture has become uniform, after which there is little difference in the rate of hydrogenation of the remaining unsaturated components. (Some of our data suggest that, to a minor degree, palmito-glycerides may be slightly more readily saturated than tri-C_{18}-glycerides. The possible influence of chain-length in this respect is being further investigated in this laboratory.)

The above conclusions, however, still leave unexplained the extreme degree of apparent selectivity shown in the production of saturated palmito-glycerides during the hydrogenation of natural fats such as cottonseed oil and pig depot fat (cf. p. 1768). Nothing approaching this degree of preferential formation of these glycerides was observed in any of the foregoing results with mixtures of equal quantities of palmito-oleo-glycerides and triolein. The proportion of palmito-oleo-glycerides in these two fats is, however, much greater than 50%, namely, about 75% and 80% respectively. We have proved that this effect is merely the result of the relative concentration of the palmito-oleo-glycerides, superimposed on the other influences which have been discussed above; for, on altering the proportions of the components, in mixtures of α-oleodipalmitin or α-palmitodiolein with triolein, we obtained the results shown below, which resemble exactly the behaviour which has been observed in the hydrogenation of cottonseed oil or pig depot fat:

Mixture and proportion of glycerides.	Hydrogenated product. Iod. val.	Fully-saturated glycerides, %.	Tristearin, %, in fully saturated glycerides.	Tristearin, %, in whole fat.
50% α-Oleodipalmitin + 50% triolein	16·8	62	39	20
75% ,, + 25% ,, ...	16·5	44	Trace	Trace
50% α-Palmitodiolein + 50% triolein	14·5	53	41	22
75% ,, + 25% ,, ...	17·4	39	5	2

Experimental.

Preparation of Mixed Triglycerides.—The fatty acids required were prepared as follows:

Oleic acid was obtained from the mixed acids of olive oil, the lead salts of which were crystallised from alcohol (cf. Twitchell, *J. Ind. Eng. Chem.*, **1921**, 13, 806) to remove palmitic acid as far as possible. In some of the earlier preparations the acids from the soluble lead salts were converted into lithium salts, and the latter crystallised from 80% alcohol (Moore, *J. Soc. Chem. Ind.*, **1919**, 38, 320T), the separated lithium oleate being thus purified to a large extent from accompanying linoleic acid. In later preparations the separation of linoleic acid was omitted, the time occupied and the concurrent loss of oleic acid both appearing unnecessarily wasteful, since it is well established that linoleic glycerides pass almost completely into oleic (or *iso*oleic) glycerides (under the conditions of hydrogenation used in this work) before any hydrogenation of the latter sets in. In all cases, the purified oleic acid was converted into methyl esters and fractionally distilled in a vacuum, when any palmitic ester remaining was eliminated in the portions of lower boiling point. The main fractions of ester, on hydrolysis, furnished the oleic acid used in the glyceride syntheses. When the lithium salt purification

had been employed, the oleic acid thus finally obtained had iodine value 89·2—90·6; when this was omitted, the iodine value of the oleic acid was 98—99 (*i.e.*, a mixture of about 90% oleic and 10% linoleic acid).

Attempts to utilise good specimens of commercial (distilled) oleic acid as the starting material were failures, the purification required being much more than in the case of the acids prepared from olive oil and the yield of purified oleic acid much less. The processes employed in the manufacture of commercial oleic acid ("oleine") involve the formation of a good deal of isomeric oleic acids and also, to some extent, hydroxylated acids. For scientific investigation it is recommended that suitable natural fats such as olive or groundnut oil are the best source of pure oleic acid, in spite of the somewhat lengthy procedure involved in separation of the latter from palmitic and other accompanying acids.

Palmitic acid was obtained from stocks of crude methyl palmitate accumulated in the laboratory in the course of ester-fractionation analyses of different fats. The crude palmitic acid was subjected to lead salt–alcohol separation to remove small proportions of oleic acid, and the recovered "solid" acids re-methylated and fractionally distilled in a vacuum to eliminate minor amounts of myristate and stearate. Hydrolysis of the main fractions of ester gave pure palmitic acid.

Stearic acid was prepared by completely hydrogenating mixed methyl oleate–linoleate esters (a stock of which had been similarly accumulated from fractionation analyses of various vegetable fats), hydrolysing the product, and crystallising the acid obtained from 80% alcohol (10 c.c. alcohol per g. acid); pure stearic acid was then readily obtained.

Preparation of α-Monoglycerides.—The fatty acid was heated at 160° for 4 hours, and subsequently at 180° for 2 hours, with an equal weight of glycerol and of phenol in presence of 0·1% of camphor-β-sulphonic acid, and the monoglycerides isolated, according to the method of Hilditch and Rigg (*loc. cit.*). Quantities of 50—80 g. of acid were used at a time, the yield of monoglyceride being approximately equal to the weight of acid taken.

By this means the following monoglycerides were obtained: mono-olein, sap. equiv. 353·5—354, iod. val. 73—74 (calc.: sap. equiv. 356, iod. val. 71·6), containing 95—96% α-mono-olein; monopalmitin, sap. equiv. 325—326 (calc., 330), containing 92—93% α-monopalmitin; monostearin, sap. equiv. 353—354 (calc., 358), containing 91—92% α-monostearin.

Conversion of α-Mono- into Mixed Tri-glycerides.—The monoglyceride was heated (without solvent) with slightly more than the amount of fatty acid necessary to convert it into triglyceride, in presence of 0·3% of camphor-β-sulphonic acid, at 160—180° in a vacuum for about 6 hours. At first, the amount of fatty acid employed was 15—20% more than the theoretical weight required, but it was observed that, to a certain extent, interchange of acyl groups took place (*v. infra*), and that this was lessened by using a smaller excess of acid, namely, 5%. This smaller excess was found sufficient to ensure complete conversion into triglycerides. The following products were obtained:

α-Oleodipalmitin, from α-mono-olein and palmitic acid, sap. equiv. 279—280, iod. val. 34·5—36·0 (calc.: sap. equiv. 277·3, iod. val. 30·5). From the analytical figures, the product contains about 93% of α-oleodipalmitin. It was employed without further purification.

α-Oleodistearin, from α-mono-olein and stearic acid. When 15% excess of stearic acid was used, the product contained appreciable amounts of tristearin. It was therefore crystallised several times from ether (10 c.c. per g.) at 0°; nearly 15% of tristearin (m. p. 70·5—71°) then separated. The ether-soluble material, after crystallisation from acetone at 0°, melted at 45—47°. The amount of tristearin produced was much less when only 5% excess of stearic acid was used in the esterification. The α-oleodistearin (*ca.* 95% pure) used in the hydrogenation experiments was purified as described from tristearin by removing the latter by crystallisation from ether.

α-Palmitodiolein, from α-monopalmitin and oleic acid, sap. equiv. 285, iod. val. 58·4 (calc.: sap. equiv. 286, iod. val. 59·2). The small excess of unesterified acids recovered from the preparation had an iodine value (83) lower than that of oleic acid (90), indicating as usual a small amount of interchange of acyl groups. The product, however, from the analytical data, contained at least 90%, and possibly as much as 95%, of palmitodiolein.

α-Stearodiolein, from α-monostearin and oleic acid. Here, again, using 15% excess of oleic acid, some interchange of acyl groups occurred and some tristearin and oleodistearin were observed in the final product. These were removed by crystallisation of the latter from acetone at 0°. The most soluble portion (sap. equiv. 296, iod. val. 66·5) was used in the hydrogenation experiments; it was now free from oleodistearin and tristearin, but evidently contained about 10% of triolein.

Triolein (sap. equiv. 295, iod. val. 87·0; calc.: sap. equiv. 295, iod. val. 86·2) was prepared by direct esterification, at 160° in a vacuum, of glycerol with excess of oleic acid in presence of 0·2% of camphor-β-sulphonic acid.

Preparation of β-Oleodistearin from Natural Sources.—The synthetical preparation of β-oleodistearin in quantity is difficult and, since it has been shown (Hilditch and Saletore, *J. Soc. Chem. Ind.*, 1931, **50**, 468T; 1933, **52**, 101T) to occur in quantity in the seed-fats of *Allanblackia Stuhlmannii* and *Pentadesma butyracea*, it was obtained from these.

β-Oleodistearin was prepared from *Allanblackia* fat by repeated crystallisation of the latter from acetone and, subsequently, from ether. The material finally obtained (60% of the weight of the original seed-fat) had sap. equiv. 294, iod. val. 30 (calc.: sap. equiv. 296, iod. val. 28·6).

β-Oleodistearin from *Pentadesma* fat was less pure, because this fat also contains a certain proportion of oleopalmitostearin. By repeated crystallisation a specimen of crude β-oleodistearin (sap. equiv. 291·3, iod. val. 29·9) was finally obtained. The component acids present in this (determined by ester-fractionation) were palmitic 5, stearic 61, oleic 34% (mol.), so that its glycerides consisted approximately of 85% β-oleodistearin and 15% oleopalmitostearin.

A product containing about 63% of oleopalmitostearin was prepared by crystallisation of pig depot fat (1500 g.) from acetone, a sparingly soluble fraction (sap. equiv. 283, iod. val. 41·5) being finally obtained. The component acids of this material, determined by ester-fractionation, were palmitic 38·2, stearic 23·9, oleic 29·4, and linoleic 8·5% (mol.), whilst oxidation with permanganate in acetone showed that it contained 12% of fully-saturated glycerides [the acids in which were palmitic 48, and stearic 52% (mol.)]. These figures correspond with the following component glycerides in the whole fat: oleopalmitostearin 63%, palmitodiolein 25%, palmitostearins 12%.

Partial Hydrogenation of Triolein, Stearodiolein, and Palmitodiolein.—Triolein hydrogenated to iodine value 32·2 (cf. p. 1770). The hydrogenated product (99 g.), crystallised from 500 c.c. of acetone at 0°, deposited 75 g. of solid (iod. val. 25·8) and left in solution 24 g. (iod. val. 52). The solid fraction (75 g.) was systematically crystallised three times from ether at room temperature and finally gave 16 g. (iod. val. 3·8) of a least soluble fraction and 59 g. (iod. val. 31·1) of ether-soluble glycerides. From the iodine values of these fractions it follows that the composition of the hydrogenated product, iod. val. 32·2, was approximately 15% tristearin, 57% oleodistearin, and 28% dioleostearin.

Triolein hydrogenated to iodine value 21·2 (cf. p. 1770). Systematic crystallisation from ether gave a least soluble fraction (27 g., iod. val. 3·5) and ether-soluble fractions amounting in all to 50 g. (iod. val. 29·1). The composition of the hydrogenated material of iodine value 21·2 was therefore approximately 31% tristearin, 64% oleodistearin, and 5% dioleostearin.

α-Stearodiolein hydrogenated to iodine value 13·5 (cf. p. 1770). Crystallisation from ether yielded 25 g. of sparingly soluble material (iod. val. 1·7) and 36 g. of more soluble products (iod. val. 25·9), leading to an estimated composition of 53% tristearin and 47% oleodistearin.

The ether-soluble products isolated from the above three products of partial hydrogenation were recrystallised from ether and then possessed the following melting points: (*a*) from triolein hydrogenated to iod. val. 32·2, 51—53°, (*b*) from triolein hydrogenated to iod. val. 21·2, 49—51°, (*c*) from partly-hydrogenated stearodiolein (iod. val. 13·5), 48—50°. These melting points, however, are of little significance as a guide to whether α-oleodistearin (m. p. 45—47°) or β-oleodistearin (m. p. 43—44°) is present, because during hydrogenation both oleo- and "*iso*oleo-" (mainly elaido-)glycerides are produced. The presence of unsaturation in the α- or β-positions of the glycerides in the hydrogenated products must therefore be examined by reference to the corresponding azelao-glycerides produced when the materials are oxidised by potassium permanganate in acetone (cf. p. 1770). Each product was oxidised by this method, and the greater part of the mono-azelao-disaturated glycerides recovered by separation of their sodium or potassium salts from solution in ether as described by Hilditch and Saletore (*loc. cit.*). The melting points of the azelao-glycerides thus obtained, after successive crystallisations from acetone or light petroleum, are given in the table which follows:

	Azelao-glycerides, g.	M. p. after successive crystallisations. 1st acetone.	2nd acetone.	1st petrol.	2nd petrol.	3rd petrol.
Triolein hydrogenated to iod. val. 32·2 (5·1 g.)	2·2	47—48°	48—49°	51—52°	52—54°	54°
Triolein hydrogenated to iod. val. 21·2 (6·7 g.)	2·4	50—51	50—51	50—52	52—53	54
α-Stearodiolein hydrogenated to iod. val. 13·5 (5·3 g.)	1·5	47—49	48—49	52—52·5	53—54	55

a-Palmitodiolein hydrogenated to iodine value 30·7 (p. 1770). The product (22·9 g.) was oxidised with potassium permanganate in acetone, and yielded 5·3 g. of fully-saturated glycerides, the proportion of which was thus 23%. It follows that the hydrogenated product was composed of about 53% oleopalmitostearin, 24% unchanged palmitodiolein, and 23% palmitostearins.

Hydrogenation of Mixtures of Mixed Triglycerides.—The relevant data for the hydrogenations referred to in the course of this paper are tabulated below:

Mixture.	Hydrogenated product.		
		Fully-saturated glyceride present.	
	Iod. val.	% (*mol.*).	Tristearin content, % (*mol.*).
50% a-Oleodistearin + 50% a-oleodipalmitin	16·0	51	34
50% Oleodistearin [1] + 50% ,,	14·0	51	37
50% β-Oleodistearin (*Allanblackia*) + 50% oleodipalmitin	15·5	54	69
50% ,, (*Pentadesma*) + 50% oleodipalmitin	13·7	59	43
50% ,, (*Allanblackia*) + 50% oleopalmitostearin [2]	15·4	47	47
50% ,, (*Allanblackia*) + 50% oleopalmitostearin [3]	13·6	58	47
50% a-Palmitodiolein + 50% a-oleodipalmitin	15·3	55	*
50% a-Stearodiolein + 50% ,,	13·9	55	37
50% a-Oleodistearin + 50% a-palmitodiolein	16·1	51	62
50% a-Stearodiolein + 50% oleopalmitostearin [3]	15·9	51	23
50% Triolein + 50% a-oleodipalmitin	25·0	17	Nil
50% ,, + 50% ,,	15·8	52	39
25% ,, + 75% ,,	16·5	44	Nil
50% ,, + 50% a-palmitodiolein	29·0	14	Nil
50% ,, + 50% ,,	14·5	53	41
25% ,, + 75% ,,	17·4	39	5

* 44% Palmitodistearin and 56% dipalmitostearin.

[1] Partly-hydrogenated triolein (ether-soluble fraction, iod. val. 29·1, p. 1773).

[2] Isolated from pig depot fat (63% oleopalmitostearin, 25% palmitodiolein, 12% palmitostearins).

[3] Semi-hydrogenated a-palmitodiolein (53% oleopalmitostearin, 24% palmitodiolein, 23% palmitostearins).

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371. *The Dissociation Constants of Alkyl-substituted Benzoic and Phenylacetic Acids.*

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Accurate values of $K_{\text{therm.}}$ for various alkyl-substituted benzoic and phenylacetic acids have been determined in order to ascertain whether they provide further information regarding the validity of the hypothesis of mesomeric electron-release by alkyl groups postulated by Baker and Nathan (J., 1935, 1884).

The relative order of acid strength of the phenylacetic acids (in which such mesomeric effect should be of minor importance) is that anticipated on the basis of the relative inductive (+ *I*) effects Me < Et < Pr^{β} < Bu^{γ}. In the benzoic series, small but irregular differences are established, the ethyl and the *iso*propyl derivative being stronger acids than the methyl and the *tert.*-butyl compound.

The results are discussed on the basis of two alternative points of view.

ACCURATE data for the strengths of *p*-alkylbenzoic acids were of great interest to one of us because it was considered probable that a study of the ionisation equilibrium might provide information concerning the relative electron-release capacities of alkyl groups, and thus afford a further test of the validity of suggestions recently made regarding the mechanism of such electron-release (Baker and Nathan, J., 1935, 1884). Since data of the type required have now been made available for a large number of substituted aromatic acids, we have

collaborated in the determination of the values of $K_{therm.}$ for a series of *p*-alkylsubstituted benzoic acids (in which there is complete conjugation between the alkyl substituent and the carboxyl group) and phenylacetic acids (in which such conjugation is broken by the intercalation of the methylene group). The results are in the following table.

Values of 10^5 $K_{therm.}$ *for* p-R·C_6H_4·CO_2H *and* p-R·C_6H_4·CH_2·CO_2H *in water at* 25°.

R =	H.	Me.	Et.	Pr^β.	Bu^γ.
R·C_6H_4·CO_2H	6·27 [1]	4·24 [2]	$4{\cdot}43_5$	4·43	3·98
R·C_6H_4·CH_2·CO_2H	4·88 [3]	4·27 [4]	4·24	4·06	$3{\cdot}82_5$

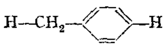
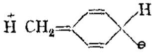
[1] J., 1934, 1888. [2] *Ibid.*, p. 161. [3] J., 1936, 644. [4] This vol., p. 1008.

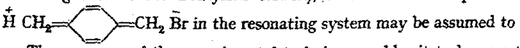
The values for *p*-ethyl- and *p*-*iso*propyl-benzoic acids and those for *p*-methyl- and *p*-ethyl-phenylacetic acids are indistinguishable, but the other differences are real, the mean deviation from the mean being usually 0·5—1·0%, and in no case as large as 2%.

Earlier and less accurate data are available for 10^5 $K_{class.}$ for *p*-*iso*propylbenzoic acid (5·0; Ostwald, *Z. physikal. Chem.*, 1889, **3**, 389) and for *p*-*tert.*-butylbenzoic acid (4·2; Shoesmith and Mackie, J., 1936, 300): our values of 10^5 $K_{class.}$ for these acids are $4{\cdot}50_5$ and $4{\cdot}02_5$, respectively. The foregoing authors did not determine Λ_0 by sodium salt measurements, but merely computed the value on the basis of the number of atoms contained in the molecule. The values so obtained were considerably lower than ours, and this fact would partly account for the higher dissociation constants.

Discussion (J. W. Baker).

The mesomeric type of electron-release by alkyl groups attached to a conjugated system was assumed (Baker and Nathan, *loc. cit.*) to have its origin in the existence of resonance (involving the duplet of electrons which form the C–H bond) between the various structures of the two general types (I) and (II).

(I.)   (II.)

Since the necessary system is present in respect of three C–H bonds in a methyl substituent, two in ethyl, one in *iso*propyl, and is absent in *tert.*-butyl, such electron-release towards the benzene ring would decrease in the order Me>Et>Pr^β>Bu^γ. Superimposition of this effect upon the ordinary inductive (+ *I*) effect, which increases in the order Me<Et<Pr^β<Bu^γ, should thus cause either complete or at least partial inversion of this order in the sequence which represents the relative magnitudes of total electron-release by alkyl groups. The experimental evidence (J., 1935, 1847; 1936, 226; *loc. cit.*) from kinetic studies of reactions of opposite types revealed a complete reversal of the usual inductive order for alkyl substituents, suggesting that the mesomeric electron-release was of major importance. The contribution made by structures of type (II) towards the mixed wave-function is, of course, unknown. In the resting state of the molecule it is probably small, but in activated molecules participating in a reaction it may become of great importance. Thus, for example, in the conversion of *p*-methylbenzyl bromide into a quaternary ammonium salt, as the C–Br bond becomes stretched (by solvation of the halogen or by electrostriction of the attacking base at the methylene carbon), so the relative importance of the structure  in the resonating system may be assumed to be enhanced.

The accuracy of the experimental technique enables it to be asserted with confidence that the differences now recorded in the values of $K_{therm.}$ for the various alkyl-benzoic and -phenylacetic acids are real. The question therefore arises whether they are significant as evidence regarding the relative electron-release capacities of alkyl substituents. In the alkylphenylacetic acids any mesomeric effects of the type postulated would be of minor importance, and in this series the values of $K_{therm.}$ decrease in a fairly regular sequence which is in harmony with the usual order of inductive (+ *I*) effects of alkyl groups. In the benzoic series, where such mesomeric effects should play an important rôle, a partial inversion of this order is found, but, although the average decrease in $K_{therm.}$ produced by alkyl

substitution is much greater in benzoic acid (approx. 2·0) than it is in phenylacetic acid (approx. 0·8) yet the differences in the $K_{therm.}$ values for the various alkyl-substituted acids are as large in the one series as in the other. Because of the expected damping effect of the methylene group in the phenylacetic acids, this seems difficult to understand unless some other factor is interfering. Such complications might well be introduced by differing heat capacity and entropy effects which, in the transition from absolute zero to room temperature, could easily swamp differences as small as those involved in these two series of acids. The significance of an objection of this type has been pointed out by Hammett (*J. Chem. Physics*, 1936, **4**, 613) and is discussed more fully by Dr. Dippy (below), but the present writer is of the opinion that, although the data obtained are not inconsistent with the postulates regarding the electron-release capacity of alkyl groups, it is unsafe to base any definite conclusions upon the small and irregular differences in $K_{therm.}$ which are disclosed.

Discussion (J. F. J. DIPPY).

Since different opinions may be held regarding the tractability of the present results, the writer wishes to explain his particular standpoint. The criticism is made that, although the differences in the values of $K_{therm.}$ for the various alkyl-benzoic and -phenylacetic acids are real, heat capacity and entropy effects are partly responsible for the relative order of strengths. An objection of this kind has been raised by Hammett (*loc. cit.*), who suggested that dissociation-constant data are admissible in organic discussion only if the effects of the substituents upon heat of ionisation are identical with their effects upon the change of free energy. Hammett analyses the data for the strengths of fatty and benzoic acids at various temperatures, and indicates that conclusions regarding the effects of substituents, derived from ΔH and ΔF data, are at variance.

Nevertheless, there is good reason to suppose that safe conclusions *can* be reached from values of $K_{therm.}$ for a fixed temperature.

In the first place, there is the undoubted fact that consistent and satisfactory results have attended such discussions in the past. Secondly, Hammett, in spite of the above objection, employs to his satisfaction in a later paper (*J. Amer. Chem. Soc.*, 1937, **59**, 96) accurate dissociation-constant data (water at 25°) for a series of substituted benzoic acids as a basis for the quantitative correlation of the effects of substituents in a number of organic reactions. Thirdly, there is the testing of what is admitted to be a proper theoretical objection. This is best done by making an examination of a series of acids where the strengths are much alike. Harned and his co-workers (*ibid.*, 1933, **55**, 652, 2379; 1934, **56**, 2039) have obtained thermodynamic constants (K_t) for acetic, propionic, and *n*-butyric acids at a variety of temperatures (ranging from 0° to 60° in 5° intervals), and find that K passes through a maximum (K_m at θ°). The temperature θ is somewhat different with each acid. Since, therefore, a comparison of the strengths of two acids at a fixed temperature may not be really fair, Harned (*ibid.*, 1934, **56**, 1050) states that for comparison purposes values of K_m should be employed, *i.e.*, where $\Delta H = 0$ (at temperature θ°). Reference to Harned's data for the above fatty acids makes it clear, however, that there exists no important difference between the relative values of K_m and those of K_t (*e.g.*, at 10° or 25°).

The alkyl-aromatic acids recorded in this paper are comparable with the fatty acids in that their strengths lie close together and their constitutions are all alike. It is reasonable to suppose, therefore, that the present $K_{therm.}$ data provide a satisfactory relative order capable of being used in discussion. The effects of the alkyl groups are, indeed, so much alike that it is to be expected that any investigation aimed at comparison of their effects will necessarily involve differences of small magnitude in the experimental results.

In the writer's opinion the results in both the benzoic and the phenylacetic series are quite in harmony with the Baker–Nathan theory. Dr. Baker points out above that the existence of distinct partial inversion in the benzoic series may be expected, but suggests that a complication is indicated by the fact that the differences in strength between the various alkylbenzoic acids are not greater than those between the alkylphenylacetic acids. Since, however, the effect postulated by Baker and Nathan is the same in sign as the inductive effect of the alkyl group, but decreases in magnitude in the opposite order, the operation of this effect (which is restricted to the benzoic series) would tend to reduce

the relative differences in acid strength and so account for this observation. In fact, it is theoretically possible that the K's of the alkylbenzoic acids should all be alike.

An alternative viewpoint is capable of accounting for the complete or partial inversion of the effects of alkyl groups substituted in the aromatic nucleus. If it is supposed that an effect, in a direction opposite to $+I$, is introduced on alkylation of methyl ($Bu^{\gamma} > Pr^{\beta} > Et > Me$) conclusions similar to those of Baker and Nathan will be reached. This view is different, however, in that it *attributes greatest abnormality to the* tert.*-butyl substituent*, and not to methyl.

An apparently linear relationship connecting the dissociation constants of substituted benzoic and phenylacetic acids with the dipole moments of substituted benzenes, recently put forward by the author (*Nature*, 1937, **139**, 591; cf. Dippy and Lewis, this vol., p. 1008), should be capable of testing this alternative interpretation. Only the dipole moments of toluene and *tert.*-butylbenzene are known at present * (the latter is due to Le Fèvre, Le Fèvre, and Robertson, J., 1935, 480); nevertheless, the corresponding acids happen to be the most interesting. The methyl acids in both the benzoic and the phenylacetic series are situated on their respective straight lines (already shown by Dippy and Lewis, *loc. cit.*), but whereas *p*-butylphenylacetic acid also comes on, it is now seen that *p*-butylbenzoic acid actually falls well *above* the appropriate line. In fact, it is to be expected that the anomaly will only be sufficiently pronounced in this instance to be detected. It is thought, therefore, that *p-tert.*-butylbenzoic acid has a strength which is definitely *high*, pointing to an additional effect which facilitates ionisation.

Experimental.

Preparation of Materials.—p-*Ethylbenzoic acid.* The aldehyde (J., 1935, 1847) (2·5 g.) was treated with aqueous sodium bicarbonate and "perhydrol" and kept at room temperature for several days, with occasional stirring and addition of further quantities of solid sodium bicarbonate and hydrogen peroxide. The acid fraction was isolated in the usual manner, and the unchanged neutral oil (1·5 g.) was oxidised with 1·1 g. of powdered potassium permanganate in aqueous acetone and sodium bicarbonate at room temperature. The combined acid fractions after isolation were crystallised first from dilute alcohol and then repeatedly from ligroin (b. p. 60—80°) to give the acid, m. p. 111° (Found: C, 72·7; H, 6·6. Calc. for $C_9H_{10}O_2$: C, 72·0; H, 6·7%).

p-iso*Propylbenzoic acid.* The aldehyde was isolated as its bisulphite compound from the fraction of cumin oil, b. p. > 200°. This aldehyde, b. p. 102—104°/10 mm. (25 g.), was shaken with 22 g. of potassium hydroxide dissolved in 15 ml. of water. Much heat was developed and the mass set solid. After 18 hours the product was dissolved in water, and neutral products extracted with ether. Acidification of the aqueous liquor at − 5° with cold concentrated hydrochloric acid precipitated the acid which, after repeated crystallisation from ligroin (b. p. 60—80°), had m. p. 119—120° (Found: C, 73·7; H, 7·45. Calc. for $C_{10}H_{12}O_2$: C, 73·2; H, 7·3%).

p-tert.-Butylbenzoic acid was the specimen previously obtained (*loc. cit.*). The *p*-alkylphenylacetic acids were prepared from the appropriate benzyl chlorides (J., 1935, 1840) through the nitrile, the following being a typical procedure. 7·7 G. of *p*-ethylbenzyl chloride were refluxed with a solution of 12 g. of sodium cyanide in 50 ml. of 96% alcohol on a steam-bath for 18 hrs. After evaporation of most of the alcohol on the steam-bath, the total volume being kept constant by addition of water, the nitrile was extracted with ether. Distillation of the residue from the dried ethereal extract gave the nitrile, b. p. 127—130°/14 mm. (5—6 g.). The nitrile (5 g.) was refluxed with 20 ml. of sulphuric acid (2 parts of water to 3 of acid by vol.) on a sand-bath until the original emulsion first cleared and then quickly formed again owing to the separation of the acid (5—10 mins.). After cooling, the solid acid was extracted with ether to remove traces of carbonaceous matter, and re-extracted with aqueous sodium carbonate. The *p*-ethylphenylacetic acid, isolated in the usual manner after acidification, was crystallised first from ether–ligroin (b. p. 40—60°) and then repeatedly from ligroin alone until it had m. p. 92° (Found: C, 73·5; H, 7·35. Calc. for $C_{10}H_{12}O_2$: C, 73·2; H, 7·3%). Similarly prepared, *p-iso*propylphenylacetic acid had m. p. 52—53° after crystallisation from ice-cold ligroin (b. p. 40—60°). Much loss occurs during purification

* The dipole moments of all the relevant alkylbenzenes and alkyl*cyclo*hexanes, in the gas phase, are under investigation in collaboration with Professor S. Sugden (J. W. B.).

owing to the high solubility in this solvent (Found: C, 73·0; H, 7·9. Calc. for $C_{11}H_{14}O_2$: C, 74·2; H, 7·9%).

p-tert.-Butylphenylacetic acid was obtained by refluxing *p-tert.*-butylbenzyl bromide (3 g.) with sodium cyanide (2 g.) in alcohol (30 ml.) for 18 hours. Upon evaporation of alcohol and addition of water, the nitrile separated as an oil, which was washed with water and then hydrolysed in the usual manner. After the hot product had been filtered through glass-wool and cooled, the acid separated in fine needles, m. p. 80°.

All these acids were again crystallised from conductivity water and carefully dried before the values of $K_{therm.}$ were determined, satisfactory values for their equivalents being obtained throughout. The final m. p. data are tabulated below, together with the best values recorded in the literature.

Acid.	M. p. (corr.).	M. p. (lit.).	
p-Ethylbenzoic	111·5°	110—111°	(Fittig and König, *Annalen*, 1867, **144**, 290)
		112—113	(Aschenbrandt, *ibid.*, 1883, **216**, 221)
*p-iso*Propylbenzoic	120	117—118	(Claus, *J. pr. Chem.*, 1888, **37**, 26)
		119	(Ciamician and Silber, *Ber.*, 1912, **45**, 42)
p-tert.-Butylbenzoic	165	*164	(Kelbe and Pfeiffer, *Ber.*, 1886, **19**, 1725)
		165	(Shoesmith and Mackie, J., 1936, 300)
p-Ethylphenylacetic	92	88·5—89·5	(Bogert and Stamataff, *Rec. trav. chim.*, 1933, **52**, 584)
*p-iso*Propylphenylacetic	53·5	51—52	(Schorigin, *Ber.*, 1910, **43**, 1942)
		52	(Rossi, *Annalen*, Suppl., **1**, 139)
p-tert.-Butylphenylacetic	81·5	78—79	(Berg, *Rocz. Chem.*, 1934, **14**, 1249)

Measurements.—The conductivity measurements were made on aqueous solutions at 25° by a procedure already described (Dippy *et al.*, J., 1934, 161, 1888; 1936, 644). Since the acids were only sparingly soluble in water, their stock solutions were made up to 500 ml., except in the case of *p-tert.*-butylbenzoic acid, which was dissolved in 1 l. The water employed in the various runs had a specific conductivity of 0·9—1·0 gemmho.

In the following tables, the observations made on the six acids are summarised, details of a complete run being given in each case. The mean values of Λ_0 (acid) were obtained from conductivity measurements on the aqueous solutions of the sodium salts by the method adopted elsewhere (Dippy *et al.*, *loc. cit.*).

p-*Ethylbenzoic acid.*

Cell constant.	10^3 C.	Λ.	10^5 $K_{class.}$	10^5 $K_{therm.}$
0·07278	0·9837	73·08	4·51	4·42
	0·6879	85·80	$4{\cdot}53_5$	$4{\cdot}45_5$
	0·4771	100·0	4·49	$4{\cdot}41_5$
	0·4285	104·8	$4{\cdot}50_5$	$4{\cdot}43_5$
	0·3659	111·8	4·49	$4{\cdot}42_5$
	0·2330	134·1	4·49	$4{\cdot}44_5$

12 determinations; limits of $10^5 K_{therm.}$ 4·41—4·47.
Mean Λ_0 (acid) = 379·8.

p-iso*Propylbenzoic acid.*

Cell constant.	10^3 C.	Λ.	10^5 $K_{class.}$	10^5 $K_{therm.}$
0·07291	0·4487	101·7	4·43	4·36
	0·3416	115·2	$4{\cdot}54_5$	4·48
	0·3283	117·2	$4{\cdot}55_5$	4·49
	0·2373	133·2	$4{\cdot}53_5$	4·48
	0·1786	149·6	$(4{\cdot}61_5)$	$(4{\cdot}56_5)$

16 determinations; limits of $10^5 K_{therm.}$ 4·35—4·49.
Mean Λ_0 (acid) = 378·5.

p-tert.-*Butylbenzoic acid.*

Cell constant.	10^3 C.	Λ.	10^5 $K_{class.}$	10^5 $K_{therm.}$
0·07423	0·2028	135·6	4·06	4·02
	0·1986	136·7	4·05	4·01
	0·1865	140·0	4·06	4·02
	0·1732	142·9	3·98	3·94
	0·1701	144·1	3·99	3·95
	0·1682	145·7	4·06	4·02

12 determinations; limits of $10^5 K_{therm.}$ 3·93—4·02.
Mean Λ_0 (acid) = 378·2.

p-*Ethylphenylacetic acid.*

Cell constant.	10^3 C.	Λ.	10^5 $K_{class.}$	10^5 $K_{therm.}$
0·07278	0·6024	88·49	$4{\cdot}29_5$	$4{\cdot}22_5$
	0·3743	108·8	4·34	4·28
	0·2614	125·4	4·29	$4{\cdot}23_5$
	0·2599	125·8	$4{\cdot}29_5$	4·24
	0·2403	128·9	$(4{\cdot}22_5)$	(4·17)
	0·2016	138·6	4·26	4·22

13 determinations; limits of $10^5 K_{therm.}$ 4·22—4·28.
Mean Λ_0 (acid) = 378·5.

p-iso*Propylphenylacetic acid.*

Cell constant.	10^3 C.	Λ.	10^5 $K_{class.}$	10^5 $K_{therm.}$
0·07285	0·7617	80·30	(4·36)	(4·28)
	0·4944	95·23	4·19	$4{\cdot}12_5$
	0·4932	94·73	4·13	$4{\cdot}06_5$
	0·4025	103·5	$4{\cdot}15_5$	$4{\cdot}09_5$
	0·2843	119·5	4·15	$4{\cdot}09_5$
	0·1852	141·9	$4{\cdot}17_5$	4·13
	0·1310	160·8	4·12	$4{\cdot}08_5$

20 determinations; limits of $10^5 K_{therm.}$ 3·98—4·14.
Mean Λ_0 (acid) = 378·2.

p-tert.-*Butylphenylacetic acid.*

Cell constant.	10^3 C.	Λ.	10^5 $K_{class.}$	10^5 $K_{therm.}$
0·07423	1·248	61·81	$(3{\cdot}99_5)$	$(3{\cdot}90_5)$
	0·6955	79·41	3·89	3·82
	0·6940	79·43	3·89	3·82
	0·4018	100·4	3·86	$3{\cdot}80_5$
	0·3743	103·8	$3{\cdot}89_5$	3·84
	0·3665	104·5	3·88	3·83

5 determinations; limits of $10^5 K_{therm.}$ $3{\cdot}80_5$—3·84.
Mean Λ_0 (acid) = 377·8.

It is noteworthy that the mobilities of the anions in both the benzoic and the phenylacetic series gradually fall with increasing size of the alkyl substituent. This also obtains for *p*-toluic acid [Λ_0 (acid) = 379·7)] and *p*-tolylacetic acid [Λ_0 (acid) = 379·6 (*loc. cit.*)].

As a generalisation, it can be said that the methyl and the ethyl substituent affect Λ_0 to the same extent, whilst the branched groups *iso*propyl and *tert.*-butyl are comparable in causing a further diminution in mobility.

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372. *The Dipole Moments of Vapours. Part IV. Aliphatic Ethers and Amines. The Magnitude of Atomic Polarisation.*

By L. G. GROVES and S. SUGDEN.

Measurements are recorded of the dipole moments of a number of aliphatic ethers and amines in the vapour state. For diethyl ether a large number of observations has been made over a temperature range of 190° and the results analysed by the method of least squares. It is found that the moment deduced from the slope of the P–$1/T$ curve is 1·18 D, and that the constant term in Debye's equation has a value which gives an atomic polarisation which is only 8% of the value of P_E measured for the sodium-D line.

For three other ethers and three aliphatic amines a smaller number of observations has been made and analysed in a similar manner. In general, it has been found that the moment deduced from the slope of the P–$1/T$ curve agrees with that calculated on the hypothesis that P_A is 5% of P_E.

IN the course of our work on the dipole moments of vapours we have now examined a number of aliphatic ethers and amines. The moments * calculated from our observations are compared with those found by Sänger, Steiger, and Gächter (*Helv. Physica Acta*, 1932, **5**, 200) in Table I.

TABLE I.

Substance.	μ (G. & S.).	μ (S. S. & G.).	P_{A+E}.	P_E.	P_{A+E}/P_E.
1. Dimethyl ether	1·28	1·29	15·4	13·3	1·16
2. Diethyl ether	1·18	1·10	27·6	22·5	1·17
3. Di-*n*-propyl ether	1·18	1·02	41·3	31·7	1·30
4. Di-*n*-butyl ether	1·18	—	—	—	—
5. Methylamine	1·32	1·23	13·4	10·3	1·30
6. Dimethylamine	1·02	0·96	17·4	15·1	1·15
7. Trimethylamine	0·65	0·60	21·5	19·4	1·11

It will be seen that the agreement is good for substances 1, 6, and 7, but that there are notable discrepancies for substances 2, 3, and 5. It should be noted that our values are calculated directly from the observed polarisation at each temperature on the assumption that P_A is 5% of P_E measured for the sodium-D line. Sänger, Steiger, and Gächter determined the constants for the linear relation between P and $1/T$ by the method of least squares and thus determined μ and P_{A+E} independently. The values found by these workers for P_{A+E} are compared with P_E in the last three columns of the table; all their values of the ratio P_{A+E}/P_E are higher than 1·05 and are particularly high for those substances in which our values of the dipole moment are greater than theirs.

The determination of P_{A+E} as the constant in the Debye equation involves a considerable extrapolation (to $1/T = 0$) and it is necessary to have a large number of observations over a wide range of temperatures in order to obtain an accurate value. We have therefore made a special study of diethyl ether involving 30 measurements of the polarisation over a temperature range of 188°. These observations are set out in Table II. In general, we

* All moments are expressed in Debye units, e.s.u. × 10^{-18}.

have worked with pressures of the order of 200 mm., at which the vapour should very nearly obey the ideal gas laws. The polarisations calculated on the assumption that the density of the vapour is ideal are given in col. 3; to correct for small deviations from ideal behaviour the value of d_i/d (where d_i and d represent the ideal and the real densities of the vapour respectively) has been calculated from Berthelot's equation of state, *viz.*,

$$pv = RT\left\{1 - 0{\cdot}0703\,\frac{T_c}{T}\cdot\frac{P_c}{P}\left(6\frac{T_c^2}{T^2} - 1\right)\right\}$$

$P_{corr.}$ is then obtained by multiplying P by d_i/d. It will be seen that the correction is small and can therefore be taken as substantially correct.

TABLE II.

Diethyl Ether.

T.	p, mm.	P.	d_i/d.	$P_{corr.}$	$P_{calc.}$	Δ.	μ_2.
288°	195	54·2	0·9875	53·5	53·1	+0·4	1·18
,,	242	54·0	0·9849	53·2	,,	+0·1	1·17
,,	128	53·8	0·9920	53·4	,,	+0·3	1·18
,,	153	54·0	0·9904	53·5	,,	+0·4	1·18
332	183	50·1	0·9927	49·7	49·2	+0·5	1·19
,,	142	49·5	0·9943	49·2	,,	±0·0	1·17
,,	167	49·1	0·9933	48·8	,,	−0·4	1·16
,,	129	48·7	0·9949	48·5	,,	−0·7	1·16
349·5	131	48·3	0·9956	48·1	47·9	+0·2	1·18
,,	143	48·2	0·9952	48·0	,,	+0·1	1·18
,,	199	48·3	0·9933	48·0	,,	+0·1	1·18
375	152	45·7	0·9960	45·5	46·2	−0·7	1·15
,,	201	46·5	0·9947	46·3	,,	+0·1	1·17
,,	146	45·9	0·9961	45·7	,,	−0·5	1·16
,,	147	45·7	0·9961	45·5	,,	−0·7	1·15
,,	165	46·3	0·9956	46·1	,,	−0·1	1·17
415	137	43·8	0·9974	43·7	44·1	−0·4	1·16
,,	172	44·4	0·9967	44·3	,,	+0·2	1·18
,,	202	44·1	0·9961	43·9	,,	−0·2	1·16
,,	144	44·2	0·9972	44·1	,,	±0·0	1·17
430	151	43·0	0·9974	42·9	43·2	−0·3	1·16
,,	221	44·0	0·9962	43·8	,,	+0·6	1·19
,,	155	43·3	0·9974	43·2	,,	±0·0	1·17
,,	159	43·4	0·9973	43·3	,,	+0·1	1·17
464	271	42·1	0·9964	42·0	41·8	+0·2	1·18
,,	237	42·1	0·9968	42·0	,,	+0·2	1·18
,,	211	42·0	0·9972	41·9	,,	+0·1	1·17
476	172	41·7	0·9979	41·6	41·3	+0·3	1·18
,,	252	41·5	0·9969	41·4	,,	+0·1	1·17
,,	185	41·8	0·9977	41·7	,,	+0·4	1·18
						Mean	1·17 ± 0·01

By applying the method of least squares to the data in Table II it was found that the values of the constants in the Debye equation were

$$P = 23{\cdot}2 \pm 0{\cdot}3 + (8620 \pm 100)/T \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The values of P calculated by this equation are given in col. 6, and the differences, Δ = obs. − calc., in col. 7. From these differences the probable errors quoted in the above equation were calculated. From the second term, $\mu = 1{\cdot}18 \pm 0{\cdot}01$; this is in excellent agreement with the mean value of μ calculated from each observation and quoted in the last column, in which P_{A+E} is taken as $1{\cdot}05P_E = 1{\cdot}05 \times 22{\cdot}5 = 23{\cdot}6$. This value is a little greater than the constant term in equation (1) but the difference makes no appreciable change in the calculation of the moment.

The smaller number of observations made on the other substances referred to in Table I have been treated in the same manner, and the results are summarised in Table III. Two values of μ are quoted; of these, μ_1 is derived from the slope calculated by the method of least squares, and μ_2 is the mean of the values calculated from each observation on the

assumption that P_A is 5% of P_E. It will be seen that these two methods give substantially the same result.

TABLE III.

Substance.	No. of obsvns.	Temp. range.	Dipole moment. μ_1.	μ_2.	P_{A+E}.	P_E.	P_{A+E}/P_E.
Dimethyl ether	8	290—428°	1·29 ± 0·01	1·28 ± 0·01	13·4 ± 0·5	13·3	1·01 ± 0·04
Diethyl ether	30	288—476	1·18 ± 0·01	1·17 ± 0·01	23·2 ± 0·3	22·5	1·08 ± 0·01
Di-*n*-propyl ether ...	8	331—473	1·20 ± 0·01	1·18 ± 0·01	32·5 ± 0·4	31·7	1·02 ± 0·01
Di-*n*-butyl ether......	8	385—455	1·16 ± 0·03	1·18 ± 0·01	43·3 ± 1·0	40·8	1·06 ± 0·02
Methylamine	8	288—417	1·33 ± 0·01	1·32 ± 0·01	10·0 ± 0·6	10·3	0·97 ± 0·06
Dimethylamine	7	288—427	1·02 ± 0·01	1·02 ± 0·01	15·8 ± 0·4	15·1	1·05 ± 0·03
Trimethylamine	8	289—418	0·62 ± 0·01	0·65 ± 0·01	20·9 ± 0·2	19·4	1·08 ± 0·01
							Mean 1·04

Col. 6 gives the value of P_{A+E} obtained by the method of least squares, and this is compared with P_E in the last two columns. It will be seen that the ratio P_{A+E}/P_E is in general greater than unity, and that the use of 1·05 for this ratio is amply accurate for the calculation of dipole moments from the observed polarisations.

The differences between our results and those of Sänger, Steiger, and Gächter are probably due to the fact that these workers used higher pressures (600—850 mm. for ethyl ether) which approached the saturation pressure of the vapour. We have found with a number of substances that under such conditions the polarisation is abnormal but becomes practically independent of the pressure when this is less than half the saturation value. At constant density, which these workers used, the error due to this cause would diminish as the temperature increases, but a small error in the observed values of P at the lower temperatures would introduce a comparatively large error into the slope calculated from the Debye equation.

EXPERIMENTAL.

The polarisations were measured with the apparatus described in Part I (J., 1934, 1094). In the tables below, T is the absolute temperature, p the pressure of the vapour in mm. of mercury, P the measured polarisation in c.c., and μ the dipole moment deduced on the assumption that P_A is 5% of P_E. All the values given for P_E refer to the sodium-D line.

Dimethyl ether was prepared from pure methyl alcohol and sulphuric acid at 140°; the gas was washed with sodium hydroxide and water, and collected in concentrated sulphuric acid cooled in ice. This solution was slowly dropped into water in a flask kept cool by running water; the liberated ether, after passing through a reflux condenser cooled in ice-water, was condensed at −80°. It was finally distilled at a temperature a little below its b. p., −23°.

T.	p.	P.	μ.	T.	p.	P.	μ.	T.	p.	P.	μ.
290°	104	48·9	1·28	346°	140	43·9	1·30	428°	181	37·4	1·27
,,	96	49·1	1·28	,,	133	43·9	1·30	,,	168	37·3	1·27
,,	107	49·1	1·28					,,	158	37·7	1·29
										Mean	1·28

Diethyl ether was prepared from absolute alcohol and purified as usual. The specimen used had b. p. 34·6°/760 mm., $d_4^{20°}$ 0·7142 (I.C.T. give $d_4^{20°}$ 0·714). The experimental data for this substance are given in Table II.

Di-*n*-propyl ether was prepared from *n*-propyl alcohol. The specimen used had b. p. 88·8°/757 mm., $d_4^{20°}$ 0·7468 (I.C.T. give 0·747); $P_E = 31·7$.

331	95	59·6	1·19	445	156	52·3	1·17	473	153	51·1	1·17
,,	90	59·1	1·18	,,	152	52·9	1·19	,,	191	51·5	1·18
,,	98	59·5	1·18	,,	172	52·5	1·18			Mean	1·18

Di-*n*-butyl ether, prepared from *n*-butyl alcohol, had b. p. 140·5°/757 mm., $d_4^{20°}$ 0·7685; $P_E = 40·8$.

385	111	64·6	1·17	425	95	62·9	1·18	455	126	61·4	1·17
,,	107	65·3	1·18	,,	124	63·1	1·18	,,	136	61·7	1·18
					119	62·7	1·17	,,	120	61·8	1·18
										Mean	1·18

Methylamine. The hydrochloride was recrystallised several times from alcohol and was finally extracted with chloroform. The pure product melted at 226°. The base was liberated with concentrated potassium hydroxide, dried over lime, and condensed at −80°; $P_E = 10{\cdot}3$.

T.	*p.*	*P.*	*μ.*	*T.*	*p.*	*P.*	*μ.*	*T.*	*p.*	*P.*	*μ.*
288°	203	48·3	1·32	328°	198	43·0	1·31	417°	354	36·5	1·32
,,	195	48·6	1·33	373	233	39·6	1·32	,,	269	36·3	1·31
328	191	42·9	1·31	,,	245	39·3	1·31			Mean	1·32

Dimethylamine. The base, liberated from the purified hydrochloride, was dried over lime and condensed at −80°. After redistillation it had b. p. 7·2°/758 mm., $d_{4°}^{0°}$ 0·681 (I.C.T. give 0·680); $P_E = 15{\cdot}1$.

288	150	38·1	1·02	354	151	34·0	1·02	427	215	31·1	1·03
,,	113	38·0	1·02	,,	147	34·0	1·02	,,	191	30·5	1·01
				,,	169	33·8	1·02			Mean	1·02

Trimethylamine, purified in a similar manner, had b. p. 3·4°/755 mm.; $P_E = 19{\cdot}4$.

289	265	29·5	0·65	355	391	27·8	0·65	418	244	26·6	0·65
,,	256	29·7	0·66	,,	423	28·0	0·66	,,	417	26·8	0·66
				,,	325	27·8	0·65	,,	345	26·7	0·65
										Mean	0·65

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373. *The Dipole Moments of Vapours. Part V. Aromatic Compounds.*

By L. G. Groves and S. Sugden.

Observations are recorded of the dipole moments of 16 aromatic compounds in the vapour state. In two series of *o*-, *m*-, and *p*-isomerides it is found that the observed moments for the *m*-compounds agree with the values calculated by the simple vector addition of group moments, whilst the *o*-compounds show large discrepancies.

In this paper we record measurements of the dipole moments of a number of aromatic compounds. Most of these substances have high boiling points, and observations on the vapour can only be made over a restricted range of temperature. It has been shown in Part IV (preceding paper), however, that the atomic polarisation, P_A, can be assumed with a high degree of accuracy to be 5% of P_E, so observations at one temperature are sufficient to obtain an accurate value of the dipole moment. The data so obtained are collected in the table below.

Substance.	*μ.*	Substance.	*μ.*
o-Dichlorobenzene	2·16	*p*-Nitroanisole	5·22
m-Dichlorobenzene	1·67	Phenol	1·40
p-Dichlorobenzene	0	Anisole	1·35
o-Chloronitrobenzene	4·59	Phenetole	1·40
m-Chloronitrobenzene	3·69	*cyclo*Hexyl methyl ether	1·29
p-Chloronitrobenzene	2·78	Diphenyl ether	1·35
o-Nitroanisole	4·77	Aniline	1·48
m-Nitroanisole	4·51	Dimethylaniline	1·61

A full discussion of these results requires a detailed consideration of induction within the molecule: this discussion we shall defer to Part VI of this series. Meanwhile, it is of interest to compare the moments found for *o*-, *m*-, and *p*-isomerides with those predicted by adding vectorially the group moments acting at angles of 60°, 120°, and 180° respectively. Using for the moments of the chloro- and the nitro-group the moments recorded in Part II (J., 1935, 972) for chlorobenzene (1·73) and nitrobenzene (4·24), we have calculated the following figures:

	μ, calc.	μ, obs.		μ, calc.	μ, obs.
o-Dichlorobenzene	3·00	2·16	*o*-Chloronitrobenzene	5·32	4·59
m- ,,	1·73	1·67	*m*- ,,	3·69	3·69
p- ,,	0	0	*p*- ,,	2·51	2·78

It will be seen that the meta-compounds show substantial agreement between the observed and the calculated values. Both the ortho-compounds have moments which are considerably smaller than the calculated values, and *p*-chloronitrobenzene has a moment which is appreciably larger. *p*-Dichlorobenzene would be expected to have zero moment, and the experimental results agree with this conclusion.

Experimental.

The polarisations were measured with the apparatus described in Part I (J., 1934, 1094). In the tables below, T is the absolute temperature, p the pressure of the vapour in mm., P the measured polarisarion in c.c., and μ the dipole moment deduced on the assumption that P_A is 5% of P_E. All the values given for P_E refer to the sodium-D line.

o-Dichlorobenzene was purified by fractional distillation. The best fraction was frozen out three times and finally distilled; b. p. 179—181°/755 mm., $d_{4^\circ}^{20^\circ}$ 1·2965; $P_E = 36·0$.

T.	*p.*	*P.*	μ.	*T.*	*p.*	*P.*	μ.
420°	140	107·0	2·17	448°	101	101·6	2·15
,,	150	106·9	2·17	,,	145	101·8	2·16
						Mean	2·16

m-Dichlorobenzene prepared from 2 : 4-dichloroaniline had b. p. 172·8°, $d_{4^\circ}^{20^\circ}$ 1·287 (" International Critical Tables " gives 1·288); $P_E = 36·0$.

413	63	79·0	1·66	458	98	75·7	1·68
,,	79	79·4	1·67	,,	113	75·9	1·68
						Mean	1·67

p-*Dichlorobenzene*. The specimen used had m. p. 53·0°; $P_E = 36·0$. Two observations at $T = 434°$ and $p = 110$ and 120 gave $P = 38·1$, 38·1. Since $1·05P_E = 37·8$, the moment is zero within the limits of the experimental error.

o-*Chloronitrobenzene*. The specimen used had m. p. 32·7°; $P_E = 36·9$.

477	91	314·3	4·61	477	87	310·5	4·58
475	68	313·0	4·59	,,	75	311·4	4·59
						Mean	4·59

m-*Chloronitrobenzene*. M. p. 44·5°; $P_E = 36·9$.

483	96	212·1	3·68	483	69	212·0	3·69
,,	114	212·8	3·69	,,	81	212·7	3·69
						Mean	3·69

p-*Chloronitrobenzene*. M. p. 83·5°; $P_E = 36·9$.

483	100	138·2	2·79	483	77	137·2	2·78
,,	63	138·6	2·80	,,	81	136·7	2·77
						Mean	2·78

o-*Nitroanisole*. The specimen used had b. p. 276·8°/757 mm., $d_{4^\circ}^{20^\circ}$ 1·266 (I.C.T. gives $d_{4^\circ}^{20^\circ}$ 1·268); $P_E = 39·6$.

477	55	338·5	4·79	477	53	337·4	4·78
,,	60	336·0	4·77			Mean	4·78

m-Nitroanisole, recrystallised from alcohol, had m. p. 38°; $P_E = 39·6$.

476	65	303·6	4·50	476	42	303·8	4·50
,,	59	306·0	4·52			Mean	4·51

p-*Nitroanisole*. The specimen used had m. p. 53·7°; $P_E = 39·6$.

478	50	391·2	5·21	478	58	397·3	5·25
,,	55	391·2	5·21			Mean	5·22

Phenol, distilled in a vacuum, had m. p. 41°; $d_{4°}^{40.6°}$ 1·058 (I.C.T. gives 1·0577); P_E = 28·0

T.	*p.*	*P.*	*μ.*	*T.*	*p.*	*P.*	*μ.*
449°	68	57·0	1·42	451°	103	56·2	1·40
,,	79	56·2	1·40	,,	112	55·3	1·38
451	90	56·7	1·41			Mean	1·40

At higher pressures and lower temperatures the value of μ varied with the pressure and was less than 1·40.

Anisole. The specimen used had b. p. 154°/759 mm., $d_{4°}^{20°}$ 0·9942 (I.C.T. gives 0·994) P_E = 32·4.

403	100	61·7	1·34	403	123	61·5	1·34
,,	125	62·5	1·36			Mean	1·35

Phenetole. The specimen used had b. p. 169°/739 mm., $d_{4°}^{20°}$ 0·9651 (I.C.T. gives 0·965); P_E = 37·6.

415	95	68·0	1·39	473	96	64·8	1·39
,,	55	68·1	1·39	,,	92	64·6	1·39
,,	94	69·2	1·41	,,	101	64·9	1·40
						Mean	1·40

*cyclo*Hexyl methyl ether, prepared from sodium, *cyclo*hexanol, and methyl iodide, had b. p. 135°/753 mm., $d_{4°}^{20°}$ 0·9012; P_E = 33·9.

406	107	60·9	1·29	438	104	58·7	1·28
,,	94	60·8	1·29	473	84	57·7	1·30
438	104	59·1	1·29	,,	99	57·6	1·30
,,	95	59·8	1·31	,,	61	57·3	1·29
						Mean	1·29

Diphenyl ether. The specimen used had m. p. 27·8°; P_E = 52·8.

486	109	78·7	1·36	486	105	78·3	1·34
,,	107	78·3	1·34			Mean	1·35

Aniline, purified by fractionation over zinc dust, had $d_{4°}^{20°}$ 1·0218 (I.C.T. gives 1·0217); P_E = 30·6.

459	76	61·7	1·48	459	106	61·7	1·48
,,	104	61·4	1·48	,,	110	61·4	1·48
						Mean	1·48

Dimethylaniline, distilled over zinc dust, had $d_{4°}^{20°}$ 0·9563 (Bramley, J., 1916, **109**, 434, found $d_{4°}^{20°}$ 0·9562); P_E = 40·8.

455	75	78·2	1·62	455	83	78·4	1·62
,,	60	77·3	1·60			Mean	1·61

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374. *Liquid-phase Reactions at High Pressures. Part II. The Polymerisation of Olefins.*

By R. H. SAPIRO, R. P. LINSTEAD, and D. M. NEWITT.

The polymerisation of the following substances has been studied at temperatures of 100—160° and pressures up to 10,000 atmospheres: α-methylstyrene, αβ-dimethylstyrene, α-*iso*propenylnaphthalene, *as*-diphenylethylene, ethyl cinnamate, *iso*amylene, and Δ^γ-butenylbenzene.

α-Methylstyrene, which is polymerised only to a low degree and with difficulty by the usual methods, is readily converted at 100° and 5000 atmospheres into a glassy polymer, containing about 50 molecular units. Lower polymers, resembling those

formed in the presence of catalysts, are obtained by pressure polymerisation at higher temperatures. The formation of the lower polymers follows a different course from the high polymerisation, and high polymers cannot be made by the application of high pressure to the unsaturated dimer of α-methylstyrene.

High polymerisation among the substances studied is only realised in compounds of the type Aryl·CR:CH_2.

WHEN organic molecules polymerise they normally do so to yield substances of greater stability (at reasonably low temperatures) and lower molecular volume. Hence the reaction is one which would be expected to be favoured by increase in pressure.

Conant and Tongberg (*J. Amer. Chem. Soc.*, 1930, **52**, 1659) observed the ready polymerisation of isoprene under 12,000 atm. pressure at room temperature, and Tammann and Pape (*Z. anorg. Chem.*, 1931, **200**, 113) noted that pressures up to 3000 atm. had a greater influence on the polymerisation of olefins than on the other liquid-phase reactions studied by them. A particular advantage of high pressure as a means of effecting polymerisation is that it may bring about reaction under comparatively mild conditions, and thereby diminish disturbing influences of high temperatures and drastic catalysts.

The present paper deals with explorative work on the polymerisation of some substituted ethylenes, and particularly of α-methylstyrene, at pressures up to 10,000 atm., and at temperatures of 100—*ca.* 160°.

It is well known that styrene itself readily polymerises, under various conditions of temperature and catalyst, the degree of polymerisation being 10—1000-fold (Staudinger *et al.*, *Ber.*, 1929, **62**, 241, 2912, 2921). In general agreement with Tammann and Pape (*loc. cit.*), we find that at 100°, under 5000 atm. pressure, styrene is polymerised to a tough, colourless glass. This is slowly dissolved by cold benzene, and precipitated in a fibrous form when the solution is slowly dropped into cold methyl alcohol.

α-Methylstyrene, on the other hand, is not easily polymerised to material of high molecular weight by the usual low-pressure methods. For instance, Staudinger and Breusch (*Ber.*, 1929, **62**, 442) found that the trimer was the highest polymer produced by heating alone, or by the action of Florida earth or boron trichloride. Ultra-violet light gave only a dark gum and unchanged monomer, and stannic chloride gave 4—5% of octamer, the main product being the saturated dimer.

By employing a pressure of 5000 atm. at 100°, we have obtained 85% of a mixture of high polymers with a mean molecular weight of about 5600, corresponding to an aggregation of about 50 molecules, the remaining 15% being substantially all monomer. The results of a similar series of experiments at pressures of 2000—10,000 atm. and temperatures of 100—*ca.* 160° are given in Table I.

TABLE I.

Effect of Temperature and Pressure on the Molecular Weight and Yield of Polymers from α-Methylstyrene.

Temp.	Press., atm.	Time, hrs.	Yields, %. Monomer.	Yields, %. Low polymers.	Yields, %. High polymers.	Mean mol. wt. of high polymers.
100°	5,000	1	98—99	—	—	5,400—5,800
		14	32·6	3·4	64·0	
		96	—	—	85	
110	3,500	95	23	12	65	2,600
120	2,000	96	68·3	27·2	4·5	1,600
		260	46·0	48·7	5·3	
125 *	4,000	96	48·6	43·0	8·4	1,500
125	4,000	96	46·4	27·7	26·0	1,050
	10,000	47	21·0		79·0	1,170
150	4,000	48	18·1	81·9 (M = 370)	None	—

* 50% dilution with pure benzene.

The main points which arise are as follows: (1) Polymerisation of α-methylstyrene was induced by pressures of the order of 2000 atm. upwards at temperatures of about 100° without the aid of added catalysts. (2) Such agents as were used (dry hydrogen

TABLE II.

α-Methylstyrene.

Effect of catalysts on the yields and molecular weights of polymers.

Temp. = 120—125°; press. = 4000 atm.

Time, hrs.	Catalyst (0·25% by wt.).	Yield, %, of: Monomer.	Low polymers.	High polymers.	Mean *M* of highest polymers obtained.
96	None	46·4	27·7	26·0	1050—970
96	Dry HCl	21·5	51·9	26·6	860—940
96	Dry HCl	16·5	57·5	26·0	860—940
48	Benzoyl peroxide	55·0	26·0	19·0	1000—1070
96	$ZnCl_2$ (anhyd.)	9·5	90·5	None	370—380

chloride, benzoyl peroxide, anhydrous zinc chloride) did not appear to accelerate the reaction or lead to the production of polymers of higher molecular weight than those produced without a catalyst under the same conditions of temperature and pressure. The main effect of these added materials appeared to be to increase the yield of lower polymers at the expense of the monomer (see Table II). Zinc chloride prevented the production of any high polymer. (3) Although an increase of pressure at a given temperature did not materially affect the mean molecular weight of the higher polymers, yet it occasioned a considerable increase in the yield; *e.g.*, 26% in 96 hours at 4000 atm. and 79% in 47 hours at 10,000 atm., both experiments at 125°. (4) The effect of increased temperature was very marked, there being a decided fall in the molecular weight of the high polymers as the temperature was increased from 100° to 150°. This effect of an increase in temperature on the degree of polymerisation is well known; *e.g.*, Staudinger, Ashdown, Brunner, Bruson, and Wehrli (*Helv. Chim. Acta*, 1929, **12**, 936) recorded a decrease in the molecular weight of the polymers of indene from 3500 to 1500 when the temperature of polymerisation with stannic chloride was increased from —80° to + 110°.

The high polymers [insoluble in cold benzene-methyl alcohol (1 : 1·5), and in boiling methyl and ethyl alcohols] produced at 100° were precipitated in a fibrous form when a cold benzene solution was dropped into cold methyl alcohol. Those from experiments at 110° or higher, on the other hand, were precipitated in a powdery form under like conditions. Whereas experiments at 100° gave polymers with a molecular weight of about 5600, those produced at 110° had a molecular weight of about 2600. The molecular weight further decreased to 1100 at 125°, and to 370 at 150—155°.

The mean molecular weight of the highest polymer obtained indicated that it was still in the class of hemicolloids, on the basis of Staudinger's classification. Nevertheless, the material possessed in some respects the properties of the more complex (eucolloid) type—for example, the glassy nature, the tendency to precipitate in fibres, and some ability to swell on being moistened with solvents.

This material was not fractionated beyond the elimination of heptamer and lower polymers, and it is very probable that it contained some material of higher molecular weight, which might confer some eucolloidal properties.

To find whether the polymers produced at 100° were depolymerised by an increased temperature while the pressure was maintained constant, the following experiment was carried out. A sample of the monomer was subjected to 5000 atm. pressure for 96 hours at 100°, *i.e.*, to conditions under which 85% of polymer with a mean molecular weight of 5600 had been obtained. The temperature was then raised to *ca.* 125° during 6—8 hours, and maintained thereat for a further 78 hours while the pressure was kept constant at 5000 atm. The product yielded 85% of high polymer which was still precipitated in a fibrous form. It was not homogeneous, however, and gave molecular weight figures from 6100 to 3000. Constant values were only obtained after repeated grinding and mixing. Some depolymerisation had obviously taken place.

A further point of interest was that, although at 100° the amount of low polymers present was very small (3·4%), yet at 125° their amount was about the same as that of the high polymers (28% and 26%). The low polymers from experiments at 125° were

found to contain dimer, trimer, and possibly tetramer. At 100°, however, practically all the material which had not polymerised to high polymer was recoverable as monomer. It would seem, therefore, that under the experimental conditions two distinct types of polymerisation are possible, and that these take place at temperatures very narrowly separated. At 100° under high pressure α-methylstyrene polymerises probably by a chain mechanism to a high but not to a low polymer. At slightly higher temperatures a stepwise type of reaction becomes prominent, and low polymers can be isolated from the product. At 150° only the stepwise reaction seems to take place, and is itself limited to the production of tetramer as the highest polymer.

These findings fall into line with previous observations at ordinary pressures. Stepwise reactions leading only to low polymers are well known; *e.g.*, it has been shown that distyrene and tristyrene do not form polystyrenes (Staudinger and Steinhofer, *Annalen*, 1935, **517**, 41). Similarly, we have found that the unsaturated dimer of α-methylstyrene does not polymerise when subjected to a pressure of 5000 atm. at 100° for 91 hours. The material was recovered unchanged, and there was no sign of polymerisation or cyclisation to the saturated dimer. This fact provides convincing evidence that the polymerisation can take at least two totally different courses.

The polymerisation of α-methylstyrene by means of stannic chloride yields a large proportion of a saturated dimer, m. p. 52° (Staudinger and Breusch, *loc. cit.*; Tiffeneau, *Ann. Chim.*, 1906, **10**, 155), which has been proved by Bergmann, Taubadel, and Weiss (*Ber.*, 1931, **64**, 1493) to be a derivative of indene. No such material could be isolated from the dimer produced in experiments at 125° without a catalyst, even when the products were seeded with a preparation of the saturated dimer and kept for some months in the dark, with occasional cooling and scratching. They were all unsaturated towards bromine in carbon tetrachloride. It is clear, therefore, that the dimer prepared under high pressure is essentially an open-chain compound, probably identical with that of Klages (*Ber.*, 1902, **35**, 2639), and that the application of pressure is insufficient to close the indene ring in the absence of a catalyst.

Other Substituted Ethylenes.—Comparative experiments have also been carried out with αβ-dimethylstyrene, *as*-diphenylethylene, *iso*propenylnaphthalene, ethyl cinnamate, Δ^{γ}-butenylbenzene, and *iso*amylene. The results are summarised in Table III.

TABLE III.

Substituted Ethylenes other than α-Methylstyrene.

		Experimental conditions.			Polymers.		
Substance.	Formula.	Press., atm.	Temp.	Time, hrs.	Yield, %.	*M*.	Order of polymer.
Unsat. dimer of α-methylstyrene.....	$CPhMe_2{\cdot}CH{:}CMePh$	5,000	100°	91	No polymerisation		
αβ-Dimethylstyrene...	$CPhMe{:}CHMe$	5,000	120	96	2·3	251	2
α-*iso*Propenylnaphthalene	$C_{10}H_7{\cdot}CMe{:}CH_2$	5,000	125	166	1·9	905	5—6
		10,000	125	30	54	1270	8
as-Diphenylethylene	$CPh_2{:}CH_2$	5,000	120	68	35·5	347	2
		5,000	150	96	35·2	—	2
Ethyl cinnamate	$CHPh{:}CH{\cdot}CO_2Et$	4,000	125	240	58·5	—	—
*iso*Amylene	$CMe_2{:}CHMe$	5,000	125	96	No polymerisation		
		10,000	125	24	No polymerisation		
Δ^{γ}-Butenylbenzene...	$CH_2Ph{\cdot}CH_2{\cdot}CH{:}CH_2$	5,000	125	78	2·0	—	—
		5,000	100	96	1·9	—	—

αβ-Dimethylstyrene gave only about 2% of a polymer, with a molecular weight corresponding to *dimer*, after treatment at 5000 atm. and 120° for 96 hours. Under these conditions α-methylstyrene yields 30% of polymers with a mean molecular weight of 1100 (mainly octamer).

as-Diphenylethylene likewise yielded only *dimers*, but to a greater extent (36%). This yield was not materially altered by increase of temperature or of period of reaction. The polymers appeared to be a mixture of dimers, and no sharply melting material could be separated; they did not decolorise bromine solution in the cold, and had a melting range of 100—105°. Lebedev (*Ber.*, 1923, **56**, 2349) records an unsaturated dimer which

Bergmann and Weiss have shown to be ββδδ-tetraphenyl-Δ^{γ}-butene, m. p. 113° (*Annalen*, 1930, **480**, 49), and Bergmann and Weiss prepared a saturated dimer, m. p. 143°, which they showed to be 1 : 1 : 3-triphenyl-3-methylhydrindene.

α-*iso*Propenylnaphthalene, on the other hand, polymerised to much the same degree as did α-methylstyrene under similar conditions, but the reaction was much slower. At 125° and 5000 atm. in 166 hours there were formed only 2% of high polymer with a molecular weight of about 900. At 10,000 atm., however, 54% of polymers with a molecular weight of 1300 were produced in 30 hours at the same temperature.

Seeligmann (Diss., Karlsruhe, 1906) noted that allyl cinnamate polymerised at 210° but the propyl ester did not. Liebermann and Zsuffa (*Ber.*, 1911, **44**, 841) found that the ethyl ester polymerised most readily, particularly on distillation followed by exposure to ultra-violet light for long periods and subsequent heating at 80—90°. The products were amorphous, white, infusible, sparingly soluble powders. Subsequently, Liebermann and Kardos (*Ber.*, 1913, **46**, 1055) found that polymerisation of allyl cinnamate by heat yielded products easily hydrolysable with alkali; whereas ultra-violet light yielded quite distinct polymers, resistant to hydrolysis under the same conditions.

At a pressure of 4000 atm. and a temperature of 125° we obtained a 58% yield of powdery polymer of ethyl cinnamate. It did not affect polarised light, and was therefore probably amorphous. It melted with decomposition in a sealed tube at about 320°, but sublimed in an open tube. Liebermann and Zsuffa's poly-ethyl cinnamate (*loc. cit.*) depolymerised and distilled at 273°, yielding ethyl cinnamate. The pressure polymer was easily hydrolysed by alcoholic potash, and would therefore appear to have a structure similar to that of the polymer obtained by heating allyl cinnamate.

We have been unable to detect any polymerisation of *iso*amylene (mainly trimethylethylene) at 125° and 5000—10,000 atm.

The effect of substitution upon the tendency to polymerise under high pressure is thus quite normal. The main conclusions which emerge are: (1) An aromatic group has a great positive influence provided that it is directly attached to the unsaturated centre. (2) High polymerisation among the substances studied has only been realised when this condition is satisfied and when a terminal $CH_2:C<$ group is present, *i.e.*, amongst compounds of the type Aryl·CR:CH_2. The behaviour of *as*-diphenylethylene shows that high polymerisation is not necessarily given by substances of this type under the experimental conditions used.

Experimental.

The apparatus and experimental procedure were those described in a previous paper (Newitt, Linstead, Sapiro, and Boorman, this vol., p. 876).

α-*Methylstyrene*.—Phenyldimethylcarbinol was made both by Klages' and by Tiffeneau's methods and was dehydrated following Staudinger and Breusch (*loc. cit.*). Small quantities were prepared at a time, since the hydrocarbon undergoes oxidation, even in the dark, on keeping. The purity was controlled by determination of the refractive index just before use.

The pressure product was treated by the following adaptation of Staudinger and Breusch's method. A hard or very viscous product was dissolved in cold benzene (10 c.c. per g., or 20 c.c. per g. in the case of experiments at 100°) and the cold solution was dropped slowly into 1·5 vols. of cold methyl alcohol with vigorous stirring. The precipitate was collected in the cold and washed with alcohol–benzene. It was then boiled twice with methyl alcohol (25 c.c. per g.) and twice with ethyl alcohol (25 c.c. per g.), the mixture being filtered hot each time. The solid product was pressed on a porous tile and dried for several days in a vacuum desiccator. This material, designated "High polymers" in Table I, consisted of a mixture of polymers from which heptamer and lower polymers had been removed.

If the pressure product was fluid it was first fractionally distilled up to *ca.* 200°/14 mm., and the residue was dissolved in benzene and precipitated as above. Monomer and low polymers were recovered from the filtrates and distilled fractions.

The methyl- and ethyl-alcoholic extracts were separately evaporated to dryness, and almost invariably gave negligible quantities of residue, indicating very small proportions of hexamer and heptamer.

Where a catalyst such as hydrogen chloride or zinc chloride had been used, the pressure product in benzene solution was first washed with water, dried over anhydrous sodium sulphate,

and then fractionated and precipitated. No precipitate of polymer was obtained from experiments with zinc chloride, and the polymerised material was recovered by evaporation of the solvents.

Molecular weights were determined cryoscopically in "molecular-weight" benzene, a concentration of not more than 3—4% being used. All polymers with a mean molecular weight up to 2600 gave reproducible results, but precipitated polymers containing fibrous material gave less consistent values. The constant for the solvent, determined with several hydrocarbons, and particularly with the saturated dimer of α-methylstyrene (m. p. 52°), was 54·0. Two detailed examples of the determinations are given below, the results as a whole being summarised in Table I.

1. 5000 Atmospheres, 100°, 96 hours.

	Δ.	*M*.
0·3994 G. in 11·70 g. benzene	0·031°	5870
0·4027 G. „ 11·80 g. „	0·034	5430

2. 3500 Atmospheres, 110°, 95 hours.

	Δ.	*M*.
0·4855 G. in 14·89 g. „	0·068	2600
0·4839 G. „ 15·46 g. „	0·065	2597

[Found, in (2): C, 91·2, 91·2; H, 8·4, 8·4. Calc. for $(C_9H_{10})_n$: C, 91·55, H, 8·45%.]

The highest polymer (*M* 5600) was a colourless transparent solid. It could be powdered by hammering, but not by grinding with a pestle and mortar. When the pulverised material was heated in an open tube, the first signs of softening could be detected with a lens at 185° and the first liquid at 222°. The material was completely fluid at 230°. There was no discoloration. When a layer of the powdered material was covered with benzene, the granules became coated with a transparent film, which grew slowly and after 30 minutes was double the width of the original layer. The layer adhered to the tube and persisted after several hours. In chloroform the granules rose, became coated with a gelatinous film, and dissolved fairly quickly to give a viscous solution. In ether the granules rapidly swelled and formed a button. This could easily be broken, by shaking, into particles which did not adhere to the tube. When the high polymer was precipitated from benzene it formed fibres merging into a disc with retained solvent. This hardened after evacuation in a desiccator for some days, and in that form was extremely difficult to pulverise even though very "blistered." It could be easily cut with a knife.

Low polymers from experiments at 125°. The low polymers from a number of experiments, weighing 14·3 g. and representing about 27% of the polymerisation yield, were fractionally distilled under 0·1 mm. The fractionation was then repeated. The data are given in Table IV.

TABLE IV.

Fraction.	B.p./0·1 mm.	Wt., g.	$n_D^{24°}$.	*M*.	Low polymer, %.		Total polymer, % (approx.).
a	110—120°	2·04	1·5765	234	14·3		
b	120—130	1·31	1·5772	—	9·2	42·7	13·0
c	130—175	1·40	1·5860	—	9·8		
d	175—190	1·35	1·5923	249	9·4		
e	190—210	1·13	1·60 (approx.)	—	7·9		
f	202—212	2·57	1·602 („)	315	18·0	37·6	6·5
g	212—220	1·68	1·604 („)	311	11·7		
h	> 220	0·7		—	4·9	8·4	2·6
Residue		0·5		—	3·5		
Loss		1·62			11·3		

The dimer fractions (*a*)—(*d*) were seeded with the saturated dimer (prepared by Tiffeneau's method) and kept for some months, being occasionally chilled in ice and salt and rubbed with a glass rod. No crystalline dimer could be isolated. All the fractions instantly decolorised a solution of bromine in carbon tetrachloride.

Unsaturated Dimer of α-Methylstyrene.—A sample of unsaturated dimer was prepared by heating phenyldimethylcarbinol to 120° with phosphoric acid (*d* 1·70) (Bergmann, Taubadel, and Weiss, *loc. cit.*). It was distilled four times under 14 mm., after which the first runnings did not give any crystalline saturated dimer on chilling and seeding. The sample had b. p. 172°/14 mm., and $n_D^{25°}$ 1·5670. Bergmann *et al.* (*ibid.*) record b. p. 166—167°/15 mm. As noted by them, the sample did not take up the theoretical amount of bromine even on standing with excess.

15 C.c. were subjected to a pressure of 5000 atm. at 100° for 91 hours. The product distilled completely at 172—173°/14 mm. There was no viscous or hard residue in the flask or any

blistering on its walls, such as occurs during distillation when polymers are present. The first runnings had $n_D^{25°}$ 1·5668, and the final runnings $n_D^{25°}$ 1·5673.

αβ-*Dimethylstyrene.*—A sample synthesised from ethylmagnesium iodide and acetophenone (Klages, *loc. cit.*, p. 2641), after three fractionations, had b. p. 73°/14 mm., $n_D^{25°}$ 1·5293. 13·0 G. were subjected to 5000 atm. at 120° for 96 hours. The product distilled almost completely at 74°/14 mm., the temperature finally rising to 76°. The residue (0·3 g.) had *M*, 251 [$(C_{10}H_{12})_2$ requires *M*, 264]. Hence only 2·3% of *dimer* was obtained. It did not decolorise bromine solution in the cold.

α-iso*Propenylnaphthalene.*—α-Acetylnaphthalene was freed from the β-compound by means of the picrate (Stobbe and Lenzner, *Annalen*, 1911, **380**, 95) and converted by means of methylmagnesium iodide into α-naphthyldimethylcarbinol (Grignard, *Bull. Soc. chim.*, 1896, **25**, 497). This was dehydrated with acetic anhydride as for α-methylstyrene; the hydrocarbon had b. p. 97°/0·1 mm., $n_D^{25°}$ 1·6070 (lit.: b. p. 125°/8 mm., $n_D^{25°}$ 1·6068).

A sample was subjected to 5000 atm. at 125° for 166 hours. Over 90% of the fluid distilled below 110°/0·1 mm. The residue was dissolved in benzene, precipitated, and purified as for α-methylstyrene polymers; yield 1·9% [Found: *M*, 905].

A second sample of the monomer was subjected to 10,000 atm. at 125° for 30 hours. The product was a gum with a pale greenish fluorescence. From 2·4 g., 1·3 g. of purified and dry high *polymer* were isolated by the precipitation method used for α-methylstyrene; yield 54% [Found: *M*, 1260, 1272. $(C_{13}H_{12})_8$ requires *M*, 1344].

as-*Diphenylethylene.*—The hydrocarbon ("Organic Syntheses," **6**, 32) had b. p. 148°/15 mm., $n_D^{20°}$ 1·6075 (lit.: b. p. 145—146°/14 mm., $n_D^{20°}$ 1·6085). A sample was subjected to 5000 atm. for 68 hours at 120°. Distillation of the product under reduced pressure gave 64·5% of unchanged monomer (b. p. 147°/14 mm.; $n_D^{19°}$ 1·6050). The remaining material (dimeride) was distilled at 0·1 mm. and all passed over at 215—240°, the rise in temperature being steady. The distillate, a hard resin with pale bluish fluorescence, when pulverised had m. p. 100—105°. After repeated crystallisations some prisms were isolated, m. p. 118—121°. The crude *dimer* had *M*, 347, 347 [$(C_{14}H_{12})_2$ requires *M*, 360]. A similar result was obtained in an experiment for 96 hours at 150° and 5000 atm. The dimer did not decolorise bromine in chloroform.

Ethyl Cinnamate.—15 C.c. of redistilled ester were subjected to 4000 atm. at 125° for 240 hours. The product was a stiff, highly opalescent jelly which, when pressed on a porous tile, gave a fine white powder. This was washed several times with cold ethyl alcohol and dried in a vacuum desiccator for some weeks; yield 58·5%. Repetition of the experiment for 96 hours with addition of 0·25% of dry hydrogen chloride as catalyst did not accelerate the reaction.

iso*Amylene* (*Trimethylethylene*).—The hydrocarbon prepared by dehydrating pure *iso*amyl alcohol with 10% hydrochloric acid in a sealed tube at 100° (Michael and Zeidler, *Annalen*, 1911, **385**, 257) had, after fractionation, b. p. 36·5°/765 mm., $n_D^{20°}$ 1·3868. Trimethylethylene has b. p. 38·4°/760 mm., $n_D^{20°}$ 1·3878 (Norris and Reuter, *J. Amer. Chem. Soc.*, 1927, **49**, 2633). The sample prepared probably contained a small proportion of methylethylethylene.

15 C.c. were placed in a cold pressure vessel which was then closed and heated to 125°. A pressure of 5000 atm. was applied for 96 hours. The vessel was cooled,* the pressure released, and the product distilled through a jacketed glass column 12″ × 0·5″ packed with broken glass. The product distilled completely at 36·5° and there was no solid residue. The column was drained into a micro-flask, and the collected liquid distilled very slowly. All boiled at 36·5—37·0°. The experiment was repeated at 10,000 atm. for 24 hours at 125° but no polymers were formed.

Δ^{γ}-*Butenylbenzene.*—The hydrocarbon, prepared by the action of sodium on benzyl chloride and allyl bromide (Riiber, *Ber.*, 1911, **44**, 2392), was redistilled thrice under reduced pressure. The sample used had b. p. 75°/14 mm., $n_D^{20°}$ 1·5065 (lit.: b. p. 72—73°/13 mm., $n_D^{20°}$ 1·5059). 15 C.c. were subjected to 5000 atm. at 125° for 78 hours. The product boiled almost entirely at 54—60°/0·1 mm., and only 2% of viscous material remained. A similar experiment at 100° for 96 hours gave the same result.

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* In all other experiments the pressure was released while the vessel was at the reaction temperature; in this instance the procedure was altered owing to the low b. p. of the *iso*amylene.

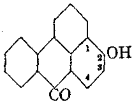
375. *Kationoid Reactivity of Aromatic Compounds. Part IV. Hydroxylation of* meso*Benzanthrone.*

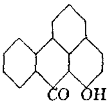
By William Bradley and G. V. Jadhav.

The direct hydroxylation of *meso*benzanthrone by means of potassium hydroxide and an oxidant is shown to yield a mixture of 2- and 4-hydroxy*meso*benzanthrone. These derivatives are formed by replacement of hydrogen situated *para* and *ortho* to a carbonyl group in the respective compounds by hydroxyl.

Many examples are known of the direct replacement of hydrogen, situated either *ortho* or *para* to a nitro- or carbonyl group attached to an aromatic nucleus, by hydroxyl or piperidyl substituents (Bradley and Robinson, J., 1932, 1254; Bradley, this vol., p. 1091). Only in the case of the hydroxylation of nitrobenzene by means of potassium hydroxide (Wohl, *Ber.*, 1899, 32, 3486. D.R.-P. 116,790) have both *o*- and *p*-derivatives been isolated from the same reaction.

A further instance has now been found in the action of potassium hydroxide on *meso*benzanthrone, which yields both 2- and 4-hydroxy*meso*benzanthrone (I and II respectively). Perkin and Spencer (J., 1922, **121**, 479) observed that 2-hydroxy*meso*-

(I.) 

 (II.)

benzanthrone was formed when *meso*benzanthrone was fused with potassium hydroxide and potassium chlorate in presence of anthraquinone, and the same compound results when other oxidants are used. The isolation of 4-hydroxy*meso*benzanthrone from the crude hydroxylation product is now described. The yield may reach 8—9% of the *meso*benzanthrone taken or 15—18% of the crude 2-hydroxy*meso*benzanthrone obtained. The 4-hydroxy*meso*benzanthrone was identified by direct comparison with an authentic specimen prepared by dehydrogenating 1-benzoyl-2-naphthol with aluminium chloride (cf. I.G., B.P. 248,791).

The separation of the isomeric hydroxy*meso*benzanthrones is facilitated by the circumstance that the 2-derivative is a strong acid soluble in sodium hydroxide solution, whereas the 4-derivative forms a salt when fused with potassium hydroxide, but this is almost completely hydrolysed on dilution with water. Further, 4-hydroxy*meso*benzanthrone is readily soluble in hot benzene, whilst the 2-derivative remains practically undissolved. The former affords a characteristic *boroacetate*. Most derivatives of *meso*benzanthrone dissolve in concentrated sulphuric acid to fluorescent orange or red solutions, but 4-hydroxy*meso*benzanthrone gives only a yellow coloration with slight greenish fluorescence, a circumstance which probably indicates the non-occurrence of oxonium salt formation in this instance. Other properties which accord with the formulation of 4-hydroxy*meso*benzanthrone as a chelate structure are the low melting point, 179° (cf. 2-hydroxy*meso*benzanthrone, m. p. 304°; Scholl and Seer, *Annalen*, 1912, **394**, 153), and the resistance of the compound to acetylation. 4-Hydroxy*meso*benzanthrone is remarkably stable to decomposition by fused potassium hydroxide, alone or when mixed with potassium chlorate.

Experimental.

*Boroacetate of 4-Hydroxy*meso*benzanthrone.*—Boroacetic anhydride (5 g.) (Pictet and Geleznoff, *Ber.*, 1903, **36**, 2219) was added to a solution of 4-hydroxy*meso*benzanthrone (2 g., m. p. 179°, prepared by the action of aluminium chloride on 1-benzoyl-2-naphthol) in acetic anhydride (50 c.c.), and the mixture boiled during 15 minutes. On cooling, crystals separated; these were collected, washed with acetic anhydride and with water, and dried. The product was dissolved in chloroform, in which it was easily soluble, and recovered by evaporation of

the filtered solution. The residue crystallised from acetic anhydride in yellow needles, decomp. 268° after shrinking at 263° (Found: C, 67·3; H, 4·0. $C_{21}H_{15}O_6B$ requires C, 67·4; H, 4·0%). The *boroacetate* is sparingly soluble in benzene, alcohol or acetic acid.

Action of Potassium Hydroxide and Potassium Chlorate on meso*Benzanthrone in Presence of Anthraquinone.*—A mixture of *meso*benzanthrone (25 g.), potassium chlorate (18 g.), potassium hydroxide (150 g.), and anthraquinone (25 g.) was added to water (37 g.) and slowly heated in an autoclave. When the temperature of the reactants reached 210°, a strongly exothermic reaction occurred and the temperature rose rapidly to 300°. The cold product was extracted with water, then with 5% sodium hydroxide solution until the extracts showed only a faint green fluorescence. Acidification afforded 2-hydroxy*meso*benzanthrone, identified as the acetyl derivative, m. p. 199—200° (Perkin and Spencer, *loc. cit.*). The undissolved portion of the product was dried and extracted with benzene (200 c.c.). A dark brown solid (1·0 g.), m. p. 125—180°, remained when the solvent was evaporated, and this was extracted with acetic anhydride and the filtered solution boiled during 15 minutes with boroacetic anhydride (2 g.). On cooling, yellow needles separated, m. p. 260° (decomp.). Most of the product was easily soluble in chloroform, and evaporation of the filtered solution gave a residue which crystallised from acetic anhydride in yellow needles; these became brown at 255° and melted with decomposition at 263° (Found: C, 67·7; H, 4·1. Calc. for $C_{21}H_{15}O_6B$: C, 67·4; H, 4·0%).

When a modified mode of oxidation was used and the temperature of the reactants was kept at 230—250°, 25 g. of *meso*benzanthrone gave 16 g. of crude 2-hydroxy*meso*benzanthrone (soluble in 7% sodium hydroxide solution), from which 1 g. of 4-hydroxy*meso*benzanthrone could be extracted with benzene. The undissolved residue, further extracted with 0·5% sodium hydroxide solution, gave 0·3 g. of a product (m. p. 160—170°), and this after recrystallisation from glacial acetic acid melted at 176—177° and did not depress the m. p. of authentic 4-hydroxy*meso*benzanthrone (Found: C, 82·7; H, 4·1. Calc. for $C_{17}H_{10}O_2$: C, 82·9; H, 4·1%). When the material which remained undissolved by aqueous alkali was dried and extracted with benzene, 4 g. of crude 4-hydroxy*meso*benzanthrone (m. p. 140—160°) were obtained. The derived boroacetate crystallised from acetic anhydride in yellow needles which became brown at 255° and melted with decomposition at 263° (Found: C, 67·4; H, 4·0%).

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376. *The Relative Reactivities of the Aliphatic Iodides. The Interaction of Alkyl Iodides with Sodium Guaiacoxide in Ethyl-alcoholic Solution.*

By John A. Mitchell.

The reactions between sodium guaiacoxide and eight *n*-alkyl iodides in alcoholic solution are bimolecular in each case, but the dependence of the velocity coefficient upon initial concentration shows that the guaiacoxide reacts in virtue of its ion, the contribution of the undissociated molecule being negligible.

The reaction between velocity coefficient and temperature conforms to the Arrhenius equation.

The reactivities of the iodides decrease rapidly from methyl to butyl and then remain nearly constant.

In the development of the theories of chemical reactivity, considerable research has been done on the reaction between phenoxides and alkyl iodides to yield ethers. Moelwyn-Hughes (*Ann. Reports*, 1935, **32**, 103) refers to reactions of the type $R_1ONa + R_2Cl \longrightarrow R_1OR_2 + NaCl$ as being chiefly ionic, involving R_1O' ions, and states that this has been justified by more reliable determinations of the degree of dissociation.

The experiments now described continue this line of investigation by a determination

of the relative reactivities of the first eight *n*-alkyl iodides in their reactions with sodium guaiacoxide in ethyl alcohol. The following conclusions have been reached.

The mechanism of the reaction conforms with Acree and Shroder's equation for dual catalysis (J., 1914, 105, 2582), *viz.*, $k = \alpha k_i + (1 - \alpha)k_m$, where k, referred to as k_0 in these experiments, represents the bimolecular velocity constant at the hypothetical time zero, at which time the exact value of α, the degree of dissociation of the sodium guaiacoxide, which behaves as a weak electrolyte, is known; k_i and k_m relate to the ion and the undissociated molecule respectively.

The reactions now considered are bimolecular (but see below). They conform closely to the Arrhenius equation, $k = Ze^{-E/RT}$, the graph connecting log k_i with $1/T$ being linear.

The reactivities of the *n*-alkyl iodides fall rapidly from methyl to butyl iodide and then remain more or less constant.

That the observed velocities are predominantly due to the interaction of the guaiacoxide ions with the alkyl iodide is inferred from the following results: (1) k_m is negligibly small; (2) for a constant concentration of ethyl iodide, k_0 increases as the guaiacoxide concentration decreases; (3) addition of a neutral salt, sodium iodide, produces a 'secondary salt' effect; (4) the probability factor P in $k_i = PZe^{-E/RT}$ is of the magnitude usually associated with reactions in which one of the reacting species is an ion.

Experimental.

Separation of the Products.—A mixture of sodium guaiacoxide with rather more than the equivalent of methyl iodide, and 5% of guaiacol to prevent alcoholysis, was refluxed for many hours. The alcohol was distilled off, the guaiacol removed by sodium hydroxide solution, and the guaiacol methyl ether extracted by ether, fractionally distilled, and weighed. This method was repeated for other iodides and gave liquid products of definite b.p.: the yields and b.p.'s are given below.

Guaiacol ether.	Yield, %.	B.p.	Guaiacol ether.	Yield, %.	B.p.
Methyl	88·9	206—207° *	Butyl	85·0	244—246°
Ethyl	90·2	217—218	Amyl	89·1	262—266
Propyl	84·2	227—230	Hexyl	84·0	280—284

* Beilstein, 1923, Band 6, 771; B.P. 205,206.

Measurement of the Velocity Constant k_0.—The method in most respects was similar to that of Segaller (J., 1913, 103, 1157) in regard to the purification of the alcohol, the storage of the alkyl iodides, the preparation of equivalent and non-equivalent mixtures, their immersion in a thermostat, and their titration at different intervals of time.

The bimolecular constant was calculated from the equation $k = (C_2 - C_1)/C_1C_2\ (t_1 - t_2)$, where C_1 and C_2 are the concentrations (g.-mols./l.) of the guaiacoxide at t_1 and t_2 minutes respectively. By extrapolating the graph of $1/y$ against t, where y is the titre in c.c., the hypothetical time zero was deduced. This is illustrated in Table I, which refers to the reaction with ethyl iodide at 17°, the concentration of both reagents being 0·1250N., and the titrating acid being 0·05N.

Table I.

t.	y.	t, corr.	$k \times 10^5$.	t.	y.	t, corr.	$k \times 10^5$.
Hypothetical time zero	25	0	—	70	16·70	80	5181
Working zero	23·4	10	5702	105	14·80	115	4997
17	21·18	27	5571	145	13·10	155	4887
40	18·88	50	5405	178	12·10	188	4729

These values of k were plotted against the mean time intervals, and if the positions could be connected to form a smooth curve this was extrapolated to zero-time. If the positions were not sufficiently accurately defined, the means of the first four and of the last four values of k were plotted against the corresponding mean time intervals. These two points were joined by a straight line and produced to cut the ordinate to give k_0. This method was adopted for the data in Table I and gave $k_0 = 0·057$.

The values of k_0 were plotted against concentration of reaction mixture, and values at seven concentrations (0·04—0·20N.) obtained by interpolation. Table II shows the mean values of k_0/α, the figures in parentheses representing the extreme values.

TABLE II.

k_0/a at	45°.	55°.	62·7°.
CH_3I	1·182 (1·361—1·121)	3·03 (3·30—2·76)	5·43 (5·74—5·28)
	55°.	62·7°.	72°.
C_2H_5I	0·705 (0·756—0·660)	1·495 (1·565—1·416)	3·34 (3·54—3·14)
C_3H_7I	0·275 (0·295—0·261)	0·563 (0·580—0·549)	1·319 (1·380—1·267)
C_4H_9I	0·250 (0·274—0·231)	0·522 (0·573—0·491)	1·096 (1·212—1·026)
$C_5H_{11}I$	0·275 (0·301—0·257)	0·526 (0·554—0·497)	1·143 (1·180—1·107)
$C_6H_{13}I$	0·264 (0·277—0·249)	0·565 (0·580—0·545)	1·250 (1·304—1·212)
$C_7H_{15}I$	0·273 (0·296—0·257)	0·505 (0·519—0·490)	1·268 (1·302—1·248)
$C_8H_{17}I$	0·259 (0·283—0·246)	0·495 (0·538—0·474)	1·0565 (1·074—1·020)

Determination of the Degree of Ionisation of Sodium Guaiacoxide in Alcohol.—Conductivity measurements were made at 0°, 25°, 35°, and 62·7°. The graphs of log λ_v against $\sqrt[3]{c}$ at these temperatures were drawn, and the equivalent conductivity at infinite dilution (λ_∞) for the solution at 35° found by extrapolation to be 49·77. For the other three temperatures values of log λ_v at *equal* concentrations were obtained by interpolation, and these values were plotted against log λ_v at 35°, the linear parts of the graphs being extended until they cut the ordinate drawn from that point on the abscissa which represented log 49·77. These points of intersection were taken as the equivalent conductivities at infinite dilution for the three temperatures; thus, at 0°, 25°, and 62·7°, λ_∞ = 28·7, 43·11, and 65·46 respectively.

The degrees of dissociation (α) were calculated for these four temperatures, and those for 45° and 55° were obtained from the graphs of α against temperature at different concentrations and of α against concentration at the required temperatures (see following table).

Concn. (N.)	0·04	0·05	0·06	0·08	0·10	0·11	0·14	0·17	0·20	0·25
$a_{45°}$	0·133	0·1207	0·1117	0·0988	0·090	0·087	0·0794	0·073	0·0678	
$a_{55°}$	0·1266	0·1153	0·1065	0·0938	0·0855	0·0828	0·0753	0·0697	0·0648	0·0590
$a_{62·7°}$	0·1211	0·1108	0·1024	0·0899	0·08203	0·0793	0·0727	0·0674	0·0626	
$a_{72°}$	0·115	0·1051	0·0973	0·0852	0·0778	0·0753	0·0689	0·064	0·0599	

Discussion of Results.—Relative reactivities of the alkyl iodides. From the values of k_0 the relative reactivities were calculated, that of propyl iodide being taken as 10 in each case:

Temp.	Methyl.	Ethyl.	Propyl.	Butyl.	Amyl.	Hexyl.	Heptyl.	Octyl.
55·0°	110·0	25·6	10	9·08	10·0	9·61	9·92	9·41
62·7	96·5	26·6	10	9·28	9·34	10·10	8·97	8·79
72·0	86·8	25·3	10	8·31	8·67	9·48	9·61	8·01

The rapid fall of reactivity from methyl iodide to propyl iodide, followed by more or less constant values for the higher homologues, has also been found by Segaller (*loc. cit.*) and Hardwick (J., 1935, 144).

Values of k_i *and* k_m. The dual hypothesis was tested by evaluating k_i and k_m from Acree's equation (p. 1793); in every case k_m was very small compared with k_i. Further evidence that undissociated molecules did not appreciably contribute to the reaction was provided by two methods.

(1) The velocity constants showed little change in k_0 when the initial concentration of the iodide was varied but that of the guaiacoxide was kept constant (Table III, *a*), whereas in experiments of the converse type, k_0 increased with diminishing initial guaiacoxide concentration in such a manner as to give a linear graph when plotted against α for the appropriate guaiacoxide concentrations (Table III, *b*).

TABLE III.

(*a*) Temperature 55°. $[C_7H_7O_2Na]$ = 0·120N.

$[C_2H_5I]$	0·080	0·120	0·240
$k_0 \times 10^4$	559	570	581

(*b*) Temperature 55°. $[C_2H_5I]$ = 0·240N.

$[C_7H_7O_2Na]$	0·24	0·22	0·20	0·17	0·14	0·12	0·10	0·08	0·06	0·04
α	0·0600	0·0622	0·0648	0·0697	0·0753	0·0801	0·0855	0·0938	0·1065	0·1266
$k_0 \times 10^4$ ...	459	469	482	505	544	581	632	694	793	957
$k_0 \times 10^4/\alpha$	7649	7541	7437	7246	7224	7254	7391	7399	7446	7558

(2) Addition of various weights of sodium iodide (2—8 g.) to 100 c.c. of a 0·12N-reaction mixture containing ethyl iodide at 55° led to diminution of the velocity constant by 28—45%. This would appear to be due to a secondary salt effect in which the dissociation of the sodium guaiacoxide was depressed by the increase in the concentration of the common sodium ion. Moreover, addition of guaiacol ethyl ether to an equivalent 0·12N-mixture at 55° produced only a negligible effect, decreasing k_0 from 0·057 to 0·0565.

Heats of activation. On the assumption that k_m is negligibly small, the ionic velocity coefficient (k_i) is equal to k_0/α. The mean values of k_i are set out in Table II, and from these were calculated the temperature coefficients, which were approximately 1·7—2·6 for 10°, and the heats of activation, which ranged from 18,101 to 20,708 cals./g.-mol. For the ethyl iodide reaction, E was 20,588, which agrees with Moelwyn-Hughes's value of 21,300 ± 700 (J., 1933, 1578).

The molecular statistics of the reactions. Substitution of k_0/α for k in the equation $k = PZe^{-E/RT}$ led to values for P of 0·04—2·96, which indicated that these reactions fall into line with those of normal specific velocity, tabulated by Moelwyn-Hughes (*Chem. Reviews*, 1932, **10**, 241), where one of the reacting species is an ion.

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377. Sophora *Alkaloids. Part I. The Alkaloids of the Seeds of* S. microphylla, *Ait.*

By LINDSAY H. BRIGGS and J. RICKETTS.

The seeds of *Sophora microphylla* are shown to contain methylcytisine, matrine, cytisine, a *base*, m.p. 293—296° (possibly $C_{15}H_{22}O_4N_2$), and a *base*, m.p. 168—171°.

THE presence of alkaloids is a characteristic of many of the natural order *Leguminosæ*, including the *Sophora* genus (cf. Wood, *Pharm. J.*, 1878, **3**, 1047; Greshoff, *Ber.*, 1890, **23**, 3537; Plugge, *Arch. Pharm.*, 1895, **233**, 430; Plugge and Rauwerda, *ibid.*, 1896, **234**, 685; Nagai, *J. Pharm. Soc. Japan*, 1899, 84; Kondo and co-workers, see Tsuda, *Ber.*, 1936, **69**, 429 for earlier references; Orékhov and co-workers, *ibid.*, 1935, **68**, 820 and earlier references).

In New Zealand the genus *Sophora* is represented by three species and the seeds of one of them, *S. microphylla*, Ait., syn. *Edwardsia microphylla* (Maori name " Kowhai "), have now been investigated. From the crude alkaloid fraction (1—2·5% yield) five different alkaloids have been isolated, *viz.*, methylcytisine and matrine in approximately equal amounts, cytisine and two other bases, the last three in less than 1% of the total alkaloid fraction. Although cytisine commonly occurs in *Sophora* species, methylcytisine has not hitherto been isolated from plants of this genus but only from the closely allied plants *Leontice thalictrum*, L., syn. *Caulophyllum thalictroides*, Mich. (Power and Salway, J., 1913, **103**, 191), *Thermopsis lanceolata*, R. Br., syn. *Sophora lupinoides* (Orékhov, Norkina, and Gurevitsch, *Ber.*, **1934**, **67**, 1394), and *Anagyris foetida* (Ing, J., 1935, 1053). Matrine itself occurs in isomeric forms and further evidence indicates that some of the derivatives also occur in isomeric forms. Two of the bases are possibly new, but sufficient material was not available for complete investigation. They do not give the Van de Moer reaction and thus probably do not contain the cytisine nucleus.

Investigations on this and other species endemic to New Zealand are being continued.

EXPERIMENTAL.

S. microphylla is a tree 9—12 m. in height endemic to New Zealand and bears extremely hard, yellow seeds, 2—3 mm. in diameter.

Three lots of seeds were examined, the best procedure being as follows. The crushed seeds

(500 g.), obtained from the same tree at Henderson, were extracted exhaustively with alcohol containing 2% of acetic acid. After removal of a fatty layer the clear yellow extract was concentrated considerably, diluted with water (2 vols.), and steam-distilled to remove the alcohol. Further insoluble material was separated, and the acid aqueous portion extracted repeatedly with light petroleum and ether. The aqueous solution was made strongly alkaline with ammonia, which caused no precipitation of solids, and extracted with chloroform until the aqueous portion no longer gave a precipitate with Mayer's reagent. The chloroform extract yielded 12 g. (2·5%) of alkaloids as a brown oil (in two other extractions yields of 1 and 1·3% were obtained). The oil was purified by distillation in a vacuum, nearly all distilling as a clear oil, b. p. 225—230°/15 mm., solidifying on cooling to a yellowish-white greasy solid. The material was excessively soluble in water and nearly all organic solvents except light petroleum and the separation of alkaloids entailed a series of fractional recrystallisations from light petroleums of different b. p.'s with systematic working up of the mother-liquors.

The distilled alkaloids were digested exhaustively with petroleum (b. p. 80—100°), giving a solution and a small insoluble residue (M). On cooling, the solutions deposited colourless crystals of mixed bases, which were recrystallised six times from petroleum (b. p. 80—100°), extracted with light petroleum (b. p. below 40°), in which base A was very sparingly soluble and base B freely soluble, and again recrystallised from petroleum (b. p. 80—100°) to give colourless needles (base A), 2—2·5 cm. long, m. p. 136°, unchanged by further recrystallisation from the same solvent (yield, 2·45 g.). In one case a sample crystallised from a large excess of light petroleum (b. p. 40—50°) in prisms, m. p. 138°.

The solvent was removed from the mother-liquors from the above recrystallisations, and the product extracted with successive portions of boiling light petroleum (b. p. below 40°), yielding a solution and a residue (N). The crystals obtained on cooling the solutions were recrystallised four times from the same solvent, giving stout needles (base B), 1—1·5 cm. in length, m. p. 77°, unchanged by further recrystallisation (yield, 3·45 g.). In one case, prisms of the same m. p. were obtained by recrystallisation with the same solvent.

The residue (N) was extracted with petroleum (b. p. 80—100°), giving a solution and a further residue (O). From the solution a further quantity of base A was worked up. The residue (O) was extracted with light petroleum (b. p. 40—50°), and the product separating recrystallised from petroleum (b. p. 100—120°) to give colourless hygroscopic plates, m. p. 148—150°, raised to 152—152·5° after four further recrystallisations from excess of petroleum (b. p. 80—100°). The yield of this base, base C, was 6 mg.

The original residue (M) was insoluble in petroleums of different b. p.'s. From boiling acetone solutions it separated as a brownish powder, base D, m. p. 293—296° (yield, 150 mg.). The base was purified through the picrate; this crystallised from water in long needles (*ca.* 1 cm. long), which charred at higher temperatures but did not melt below 350°.

In a similar experiment utilising approximately the same amount of crude alkaloid material derived from another lot of seeds, the residues from which base C was extracted gave on crystallisation from methyl alcohol–acetone 3 mg. of hair-like needles, base E, which after recrystallisation from the same solvent had m. p. 168—171°, with previous softening at 162°.

Base A.—This base, m. p. 136°, has been identified as methylcytisine (Found, in dried material: C, 70·8, 70·4; H, 7·4, 7·5; N, 13·75, 13·9. Calc. for $C_{12}H_{16}ON_2$: C, 70·6; H, 7·8; N, 13·7%). $[\alpha]_D^{20°}$ − 217° (l = 0·5, c = 2·258 in water). Power and Salway (*loc. cit.*) give m. p. 137°, $[\alpha]_D$ − 221·6°; Orékhov, Norkina, and Gurevitsch (*loc. cit.*) m. p. 132—133°, $[\alpha]_D$ − 190·0°; and Ing (*loc. cit.*) m. p. 136—137°. Methylcytisine obtained by methylation of cytisine (Partheil, *Arch. Pharm.*, 1892, **230**, 448; Rauwerda, *ibid.*, 1900, **238**, 484; Ing, J., 1931, 2200) has m. p. 134°. The alkaloid is freely soluble in water and most organic solvents, but difficultly soluble in ether and petroleum, more soluble in higher-boiling than in the lower-boiling petroleum. It gives the Van de Moer colour reaction (red coloration with ferric chloride, going blue on addition of hydrogen peroxide) typical of cytisine and its derivatives.

The aurichloride crystallised from acetone in yellow plates, m. p. 206° (decomp.). Power and Salway (*loc. cit.*) record needles, m. p. 205° (decomp.). The salt decomposed on boiling with water, depositing gold.

The picrate crystallised from hot water in long yellow needles which sintered at 220° and melted at 229°. Power and Salway obtained yellow needles sintering at 200° and melting at 229°. Ing (*loc. cit.*) records m. p. 228°.

Methiodide. After the base had been refluxed in acetone solution with methyl iodide, a methiodide separated on cooling, m. p. 247°, raised to 248° with sintering at 240° after crystallisation from methyl alcohol–water. The same methiodide, m. p. 245°, also separated on cooling

after the base had been refluxed in dry benzene solution with methyl iodide. The mother-liquors from the latter preparation deposited needles, m. p. 267°, after some months. Ing (*loc. cit.*) records m. p. 276° (decomp.).

Platinichloride. When the base in alcoholic solution was treated with choroplatinic acid, orange needles separated, m. p. 238° (decomp.). In another experiment, the base in absolute alcoholic solution containing 2—3 drops of concentrated hydrochloric acid was treated with a solution of platinic chloride in absolute alcohol. The yellow amorphous material decomposed at 267° after shrinking at 249°. It was insoluble in alcohol and acetone, but crystallised from alcohol-water in yellow plates which did not melt or decompose below 300°.

The picrolonate, from the base and picrolonic acid in absolute alcohol, crystallised from absolute alcohol in small yellow needles, m. p. 224°.

The perchlorate, from the base in ethyl acetate solution and 20% aqueous solution of perchloric acid, crystallised from absolute alcohol in long colourless needles, decomp. 250—252° (Found: N, 9·1. Calc. for $C_{12}H_{18}ON_2,HClO_4$: N, 9·2%).

The methosulphate is hygroscopic and was not obtained crystalline.

Base B.—This base, m. p. 77°, has been identified as α-matrine (Found, in dried material: C, 72·7; H, 9·5; N, 11·2; NMe, 0. Calc. for $C_{15}H_{24}ON_2$: C, 72·6; H, 9·7; N, 11·3%). $[\alpha]_D^{15°}$ + 40·93° (*l* = 1, *c* = 2·272 in water). The m. p. was not depressed by authentic specimens of α-matrine kindly provided by Professors Kondo and Orékhov (cf. Orékhov and Proskurnina, *Ber.*, 1935, **68**, 429). Matrine has so far been identified only from the root bark of *Sophora angustifolia*, syn. *S. flavescens*, by Nagai (*loc. cit.*) (cf. Tsuda, *loc. cit.*, and Kondo, *Arch. Pharm.*, 1928, **266**, 1, for references to constitutional work), from the seeds and leaves of *S. pachycarpa* (Orékhov and Proskurnina, *Ber.*, 1934, **67**, 77; Orékhov, Rabinovitsch, and Konovalova, *ibid.*, 1934, **67**, 1850), and from the seeds and leaves of *S. alopecuroides* (Orékhov, Proskurnina, and Konovalova, *ibid.*, 1935, **68**, 431). The rotations recorded for matrine are $[\alpha]_D^{10°}$ + 39·11 (Kondo, *loc. cit.*) and $[\alpha]_D^{15°}$ + 38·38° (Orékhov and Proskurnina, *loc. cit.*).

The base is freely soluble in most organic solvents, less readily in ether and difficultly soluble in petroleum but more soluble in the higher-boiling than in the lower-boiling petroleums. It is more soluble than methylcytisine in light petroleum (b. p. below 40°). It does not give the Van de Moer reaction.

The aurichloride crystallised from hot water in yellow needles and prisms, m. p. 199—200° (Kondo, *loc. cit.*, records m. p. 199°), which gradually decomposed on standing (cf. Orékhov and Proskurnina, *loc. cit.*).

Methiodide. The base in absolute methyl alcohol was refluxed with excess of methyl iodide for 6 hours. After removal of the solvent, the residue crystallised from methyl alcohol-acetone (2 : 1) in small plates, which sintered at 245°, melted at 250°, and decomposed at 254°. The mother-liquors on standing deposited long colourless needles, m. p. 304°. The methiodides recorded by Kondo and Orékhov have m. p.'s 211° and 208—209° respectively with no mention of higher-melting isomerides.

Platinichloride. The base in alcoholic hydrogen chloride was mixed with an absolute alcoholic solution of platinic chloride. On standing overnight, long orange needles separated, m. p. 229—230° (decomp.). Matrine platinichloride occurs as orange prisms, m. p. 249° (Kondo, *loc. cit.*), and orange plates, m. p. 228—230° (Orékhov and Proskurnina, *loc. cit.*), again indicating isomerism of the salts of matrine as with the free base.

Picrate. This salt separated as an oil after the base and picric acid were mixed in hot benzene solution. It crystallised from hot water in long needles, m. p. 50—130°, the indefinite m. p. being probably due to water of crystallisation.

Hydrolysis of matrine. The base was refluxed with alcoholic potash for 3 hours and gave a crystalline residue of the potassium salt when the alcohol was removed. The residue was freely soluble in water (cf. Kondo, *loc. cit.*, and Orékhov, *loc. cit.*), but was recrystallised from alcohol containing a trace of water and ether, forming hair-like needles, m. p. 204° with darkening at 190°.

Base C.—This base, m. p. 152—152·5°, has been identified as cytisine (Found, in dried material: C, 68·9; H, 7·6; N, 14·0. Calc. for $C_{11}H_{14}ON_2$: C, 69·5; H, 7·4; N, 14·7%). The m. p. was not depressed on admixture with authentic cytisine kindly provided by Dr. Ing. The base is hygroscopic, soluble in water and most organic solvents, and insoluble in cold petroleum. It is more soluble in petroleum (b. p. 100—120°) than in petroleum (b. p. 80—100°), but the latter solvent gives a better product. It gives the Van de Moer reaction. The literature records m. p.'s from 150° to 156° (cf. Moer and Plugge, *Arch. Pharm.*, 1891, **229**, 48; Buchka and Magalhaes, *Ber.*, 1891, **24**, 253; Partheil, *ibid.*, p. 634; Ing, J., 1931, 2200).

The aurichloride crystallised from hot dilute hydrochloric acid in reddish plates, m. p. 219° (decomp.), which did not depress the m. p. of authentic cytisine aurichloride. Partheil (*Ber.*, 1890, **23**, 3201) and Gorter (*Arch. Pharm.*, 1897, **235**, 301) record m. p. 212—213°.

The picrate crystallised from aqueous alcohol in long needles or prisms, which decomposed at 278° (Clemo and Raper, J., 1935, 10, obtained yellow prisms, decomp. 270°) (Found: N, 16·2. Calc. for $C_{11}H_{14}ON_2,C_6H_3O_7N_3$: N, 16·7%).

Base D.—The base itself, m. p. 293—296°, was not obtained crystalline. It is soluble in water, methyl and ethyl alcohols, slightly soluble in ethyl acetate, and insoluble in chloroform, acetone, benzene and petroleum. It does not give the Van de Moer reaction and hence probably does not belong to the cytisine group. The m. p. so far as we are aware is the highest recorded in this group of alkaloids and for this reason it may be a new base. The *picrate* prepared from the base with alcoholic picric acid darkened and charred above 270° without melting below 370°. The picrate prepared from the crude bases containing base D exploded at 265°. On purification from hot water a little amorphous material separated, accompanied by needles (*ca.* 1 cm. long). The crystalline material was carefully separated and recrystallised from hot water (final yield, 10 mg.). It then darkened at higher temperatures but did not melt below 350° [Found: C, 46·9, 47·2; H, 4·7, 4·85; N, 15·4. $C_{15}H_{23}O_4N_3,C_6H_3O_7N_3$ (?) requires C, 46·8; H, 4·8; N, 15·6%].

Picrolonate. 0·2 C.c. of a saturated alcoholic solution of picrolonic acid was added to the base (10 mg.) in alcohol. The amorphous picrolonate which separated darkened at 250°, sintered at 257—258°, and melted at 261°.

Base E.—This base, m. p. 168—171°, was obtained in insufficient amount for analysis or for full characterisation. It is very soluble in water and methyl alcohol, moderately soluble in ethyl alcohol, and insoluble in benzene, chloroform, acetone and petroleum. It does not give the Van de Moer reaction.

The aurichloride, decomp. 211°, was obtained as a yellow amorphous precipitate on adding a solution of auric chloride to the base (*ca.* 3 mg.) in very dilute hydrochloric acid (0·15 c.c.).

The properties of this base indicate that it may be a new base. [In this connection, compare sophoramine, m. p. 164—165° (aurichloride, m. p. 183—184°), isolated by Orékhov (*Ber.*, 1933, **66**, 948) from the foliage of *S. alopecuroides*; retamine, m. p. 162°, obtained from *Retama spaerocarpa* (Battandier and Malosse, *Compt. rend.*, 1897, **125**, 360, 450); and a base, $C_{15}H_{20}O_5N_2$, m. p. 170°, isolated from the young shoots of *Ulex europæus* by Clemo and Raper (J., 1935, 10).]

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378. *Chalkones: Reactivity of Some Aryl Alkoxystyryl Ketones and their Dihalides.*

By S. M. Nadkarni, A. M. Warriar, and T. S. Wheeler.

An investigation of the reaction of some aryl alkoxystyryl ketones and their dihalides has shown that the alkoxystyryl nucleus, if free from halogen, is readily halogenated. Potassium iodide in acetone removes the side-chain halogen from the chalkone dihalides, and this reaction can be used to determine the position of the halogen in the nucleus. The side-chain halogen atom adjacent to the nucleus containing the alkoxy-group is readily replaced by alkoxyl on treatment with alcohols. The dihalides with alcoholic potassium cyanide give β-aroyl-α-phenylpropionitriles. With bases the chalkone dihalides give α-halogenostyryl derivatives and β-alkoxystyryl ketones. The production of *iso*oxazoles from the dihalides by the action of hydroxylamine and the condensation of the chalkones with acetoacetic ester have also been examined. The production of benzylidenecoumaranones in place of flavones from *o*-hydroxy- or *o*-acetoxy-phenyl alkoxystyryl ketone dibromides probably depends on whether or no a β-alkoxy-compound is intermediately formed.

The dihalides of phenyl alkoxystyryl ketones (phenyl αβ-dihalogeno-β-alkoxyphenylethyl ketones) are of interest; the β-halogen atom is readily replaced by alkoxyl on treatment

with alcohols (see, *e.g.*, Dodwadmath and Wheeler, *Proc. Indian Acad. Sci.*, 1935, **2**, 439) and the majority of the *o*-hydroxy- and *o*-acetoxy-phenyl αβ-dibromo-β-phenylethyl ketones yielding benzylidenecoumaranones in place of flavones on treatment with hot alcoholic alkali contain an alkoxyl group in the β-phenyl nucleus (Warriar, Khanolkar, Hutchins, and Wheeler, *Current Science*, 1937, **5**, 475).

Halogenation of Dihalides.—*p*-Tolyl *p*-methoxystyryl and 3 : 4-methylenedioxystyryl ketones and their corresponding *dihalides* (R·CO·CHX·CHX·R′; R = *p*-tolyl; R′ = *p*-anisyl or 3 : 4-methylenedioxyphenyl; X = Cl or Br) are readily halogenated in the alkoxyphenyl nucleus to give the corresponding p-*tolyl* αβ-*dihalogeno*-β-*halogenophenylethyl ketones* (R·CO·CHX·CHX·R″; R″ = 3-X-*p*-anisyl or 6-X-3 : 4-methylenedioxyphenyl).

Action of Potassium Iodide on the Dihalides.—The position of the nuclear halogen atom in the R″ dihalides was fixed by treating these compounds with potassium iodide in acetone solution; the parent halogeno-chalkones (R·CO·CH:CHR″) were thus obtained with the separation of iodine, from presumably an intermediate unstable di-iodide (R·CO·CHI·CHIR″). The four halogeno-chalkones thus obtained were unambiguously synthesised from *p*-methylacetophenone and, respectively, 3-chloro- and 3-bromo-anisaldehyde and 6-chloro- and 6-bromo-piperonal. Further *dihalides* (R·CO·CHX·CHXR″), in which the nuclear and the side-chain halogen differed, were prepared from these halogeno-chalkones.

Action of Alcohols on the Dihalides.—When the dihalides (R·CO·CHX·CHX·R‴; R‴ = R′ or R″) were heated with methyl or ethyl alcohol, the halogen atom α to the alkoxyphenyl nucleus was replaced by alkoxyl with elimination of hydrogen halide; a number of p-*tolyl* α-*halogeno*-β-*alkoxy*-β-*phenylethyl ketones* [R·CO·CHX·CH(OR⁗)R‴; R⁗ = OMe or OEt] were thus prepared. The labile nature of one of the bromine atoms in phenyl αβ-dibromo-β-*p*-anisylethyl ketone was first observed by Pond and Shoffstall (*J. Amer. Chem. Soc.*, 1900, **22**, 658); various reasons can be adduced to show that it is the halogen atom nearer the alkoxyphenyl nucleus which is labile (Dodwadmath and Wheeler, *loc. cit.*), the simplest being that the nucleus containing the activating alkoxy-group may be expected to influence the nearer bromine atom. Bromine is more readily replaced than chlorine; the presence of a nuclear halogen atom in the alkoxyphenyl nucleus does not inhibit replacement by alkoxyl, as does the nitro-group (Dodwadmath and Wheeler, *loc. cit.*). The alkoxy-group in the α-halogeno-β-alkoxy-compounds is also labile, and can be replaced by bromine on treatment with concentrated hydrobromic acid (cf. Werner, *Ber.*, 1906, **39**, 27); the other hydrohalogenic acids do not give definite products. p-*Tolyl* α-*chloro*-β-*bromo*-β-*alkoxyphenylethyl ketones* (R·CO·CHCl·CHBrR‴) were thus obtained for the first time.

Action of Potassium Cyanide on the Dihalides.—Dodwadmath and Wheeler (*loc. cit.*) observed that the action of warm alcoholic potassium cyanide on phenyl αβ-dibromo-β-phenylethyl ketone gave β-benzoyl-α-phenylpropionitrile, synthesised by Hann and Lapworth (J., 1904, **85**, 1359) by the action of hydrogen cyanide on phenyl styryl ketone. It has now been found that some chalkone dihalides with cold alcoholic potassium cyanide give the corresponding chalkones, which are apparently intermediates in the production of the *propionitriles* [R·CO·CH_2·CH(CN)R‴] obtained in the warm from the dihalides and potassium cyanide. Possibly an unstable mononitrile [R·CO·CHX·CH(CN)R‴] or a dinitrile [R·CO·CH(CN)·CH(CN)R‴] is formed, and cyanogen halide or cyanogen is eliminated; hydrolysis may then produce hydrogen cyanide. The structure of the nitriles follows from Hann and Lapworth's result with phenyl styryl ketone (*loc. cit.*). An anomalous result was obtained when *p*-tolyl αβ-dichloro-β-3-chloro-*p*-anisylethyl ketone gave with potassium cyanide in the cold p-*tolyl* α : 3-*dichloro*-4-*methoxystyryl ketone*, the potassium cyanide acting as an alkali (see next section).

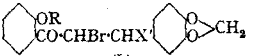
The nitriles yield the corresponding *propionic acids* [R·CO·CH_2·CH(CO_2H)R‴] on hydrolysis, though in one instance *p*-toluic acid was obtained. The use of the chalkone dihalides provides sometimes a more satisfactory synthesis of these acids than Hann and Lapworth's method using the chalkone and hydrogen cyanide. The acids are important in the production of tetralone derivatives (cf. Richardson, Robinson, and Seijo, this vol., p. 835).

Action of Bases on the Chalkone Dihalides.—The dihalides under investigation, like other αβ-dihalogeno-ketones, gave with pyridine or one molecular proportion of sodium methoxide α-halogenostyryl derivatives (R·CO·CX:CHR'''). These compounds are also obtained by heating the α-halogeno-β-alkoxy-ketones [R·CO·CHX·CH(OR'''')R'''; cf. Pond and Shoffstall, *loc. cit.*], and in one case from a dihalide by the action of potassium cyanide in the cold (see preceding section). The action of bases in excess on the chalkone dihalides may take various courses dependent on the groups present (Kohler and Addinall, *J. Amer. Chem. Soc.*, 1930, **52**, 3728). With the present dihalides, *β-alkoxystyryl ketones* [R·CO·CH:C(OR'''')R'''] were obtained usually in the form of oils (cf. for the mechanism, Dufraisse and Gerald, *Compt. rend.*, 1921, **173**, 985). These β-alkoxystyryl ketones are also formed by the action of one molecular proportion of sodium alkoxide on the α-halogeno-β-alkoxy-ketones [R·CO·CHX·CH(OR'''')R''']. They were readily hydrolysed to the tautomeric *diketones* ($R\cdot CO\cdot CH_2\cdot CO\cdot R'''$). The enolic form in which the diketones chiefly exist is probably R·C(OH):CH·CO·R'''; alkoxyl being a stronger electron source than methyl (anisole is more readily halogenated than toluene), the electron drift will be from R''' to R.

Action of Hydroxylamine on the Dihalides.—The dihalides R·CO·CHX·CHXR''' with hydroxylamine hydrochloride and alkali gave the iso*oxazoles* $R'''\cdot C\!\left\langle\begin{matrix}CH\cdot CR\\ O—N\end{matrix}\right.$; in the cases examined here, the same *iso*oxazoles were obtained by the action of hydroxylamine hydrochloride on the corresponding diketones. On the other hand the dibromide $Ph\cdot CO\cdot CHBr\cdot CHBr\cdot C_6H_4\cdot OMe$ gave 3-phenyl-5-anisyl*iso*oxazole, whereas the diketone $Ph\cdot CO\cdot CH_2\cdot CO\cdot C_6H_4\cdot OMe$ gave 5-phenyl-3-anisyl*iso*oxazole (Weygand and Bauer, *Annalen*, 1927, **459**, 123). The results are probably determined by the enolic form which preponderates in the unsymmetrical diketone; it cannot be assumed, however, that hydroxylamine necessarily attacks the keto- in preference to the hydroxy-group of the enolic form of the diketones (cf. Weygand and Bauer, *loc. cit.*).

Condensation of the Chalkones with Acetoacetic Ester.—The chalkones condense readily with acetoacetic ester to give *ethyl 6-alkoxyphenyl-4-p-tolyl-Δ³-*cyclo*hexen-2-one-1-carboxylates*, which lose carbethoxyl on hydrolysis. The resulting cyclo*hexenones* could not be converted into the corresponding phenols by addition of bromine and elimination of hydrogen bromide (cf. Petrov, *Ber.*, 1930, **63**, 901).

Production of Flavones and Benzylidenecoumaranones.—Several attempts have been made to explain the dual production of flavones and the isomeric benzylidenecoumaranones from the dibromides of some *o*-acetoxy- and *o*-hydroxy-phenyl styryl ketones (cf. Cullinane and Philpott, J., 1929, 1761). Auwers and Anschütz (*Ber.*, 1921, **54**, 1543) showed that low temperatures favoured the production of flavones, but offered no explanation of this fact. The following experiments indicate that the production of benzylidenecoumaranones in place of flavones from *o*-hydroxy- or *o*-acetoxy-aryl alkoxystyryl ketone dibromides probably depends on whether or no a β-alkoxy-compound is formed. *o*-Acetoxyphenyl αβ-dibromo-β-3 : 4-methylenedioxyphenylethyl ketone (I; R = Ac, X' = Br) gave 3' : 4'-methylenedioxyflavone (a) on direct heating, (b) with hot pyridine, (c) with hot or cold aqueous sodium hydroxide containing acetone, and (d) with cold aqueous alcoholic sodium hydroxide (Auwers and Anschütz, *loc. cit.*) or sodium carbonate: with (e) hot aqueous alcoholic sodium hydroxide (Feuerstein and Kostanecki, *Ber.*, 1899, **32**, 316) or carbonate, the 3' : 4'-methylenedioxybenzylidenecoumaran-2-one was obtained; intermediate formation of the ethoxy-compound (I; R = Ac, X' = OEt) is to be expected with hot alcohol.


(I.)

o-*Hydroxyphenyl αβ-dibromo-β-3 : 4-methylenedioxyphenylethyl ketone* (I; R = H, X' = Br) gave similar results except that with hot pyridine no definite product was obtained. o-*Hydroxyphenyl α-bromo-β-ethoxy-β-3 : 4-methylenedioxyphenylethyl ketone* (I; R = H, X' = OEt), on being heated above the m. p. or with pyridine, gave the flavone; with sodium hydroxide or sodium carbonate in hot or cold acetone or alcohol, the benzylidenecoumaranone was obtained. Once the ethoxy-compound is formed, neither

alcohol nor heat is necessary for the production of benzylidenecoumaranone; all that is required is that sodium hydroxide or sodium carbonate shall be present; a definite synthesis of these compounds is thus provided. Work in progress has shown that *o*-hydroxynaphthyl alkoxystyryl ketone dibromides, which, so far, have given only flavones with alcoholic alkali, give ethoxy-bromides and then coumaranone derivatives if the solubility of the dibromide in alcohol is increased by addition of chloroform. Chalkone dibromides derived from phloracetophenone also give benzylidenecoumaranones with alcoholic alkali (Cullinane and Philpott, *loc. cit.*) even though there is no alkoxy-group in the phenylethyl nucleus. This phenomenon is being separately investigated; it may be mentioned that heating these dibromides provides a certain synthesis of the flavones; chrysin (Warriar *et al.*, *loc. cit.*) and apigenin have thus been synthesised in this laboratory from dibromides from which previously only arylidenecoumaranones had been obtained (Kostanecki and Tambor, *Ber.*, 1899, **32**, 2260).

EXPERIMENTAL.

Compounds are numbered for brevity in cross reference. Recrystallisation was from alcohol unless another solvent is mentioned. The compounds are colourless unless otherwise stated.

Chalkones.—The following chalkones were prepared from *p*-methylacetophenone and the corresponding aldehyde in presence of alcoholic alkali (Sorge, *Ber.*, 1902, **35**, 1069): *p*-tolyl *p*-methoxystyryl ketone (1) (Petrov, *Ber.*, 1930, **63**, 901); *p*-tolyl 3:4-methylenedioxystyryl ketone (2) (Sorge, *loc. cit.*); p-*tolyl* 3-*chloro*-4-*methoxystyryl ketone* (3), m. p. 114° (Found: Cl, 12·6. $C_{17}H_{15}O_2Cl$ requires Cl, 12·4%); p-*tolyl* 3-*bromo*-4-*methoxystyryl ketone* (4), m. p. 122° (Found: Br, 24·3. $C_{17}H_{15}O_2Br$ requires Br, 24·2%); p-*tolyl* 6-*chloro*-3:4-*methylenedioxystyryl ketone* (5), m. p. 139° (Found: Cl, 12·0. $C_{17}H_{13}O_3Cl$ requires Cl, 11·7%); and p-*tolyl* 6-*bromo*-3:4-*methylenedioxystyryl ketone* (6), m. p. 150° (Found: Br, 23·2. $C_{17}H_{13}O_3Br$ requires Br, 23·2%). All these chalkones are yellow.

An improved method for the preparation of 3-chloro-*p*-anisaldehyde consists in passing chlorine (1 mol.) through an acetic acid solution of *p*-anisaldehyde, and precipitating the product by addition of water.

Side-chain Halogenation of the Chalkones.—The respective chalkones gave the following dihalides on treatment with halogen (1 mol.) in cold glacial acetic acid: p-*tolyl* αβ-*dichloro*-β-p-*anisylethyl ketone* (7), m. p. 142° (Found: Cl, 21·9. $C_{17}H_{16}O_2Cl_2$ requires Cl, 22·0%); p-*tolyl* αβ-*dibromo*-β-p-*anisylethyl ketone* (8), m. p. 172° (Found: Br, 38·9. $C_{17}H_{16}O_2Br_2$ requires Br, 38·7%); p-*tolyl* αβ-*dichloro*-β-3:4-*methylenedioxyphenylethyl ketone* (9), m. p. 140° (Found: Cl, 21·2. $C_{17}H_{14}O_3Cl_2$ requires Cl, 21·1%); p-*tolyl* αβ-*dibromo*-β-3:4-*methylenedioxyphenylethyl ketone* (10), m. p. 144° (Found: Br, 37·6. $C_{17}H_{14}O_3Br_2$ requires Br, 37·6%); p-*tolyl* αβ-*dibromo*-β-3-*chloro*-p-*anisylethyl ketone* (11), m. p. 176° (Found: halogen, 44·0. $C_{17}H_{15}O_2ClBr_2$ requires halogen, 43·8%); p-*tolyl* αβ-*dichloro*-β-3-*bromo*-p-*anisylethyl ketone* (12), m. p. 126° (Found: halogen, 37·2. $C_{17}H_{15}O_2Cl_2Br$ requires halogen, 37·6%); p-*tolyl* αβ-*dibromo*-β-6-*chloro*-3:4-*methylenedioxyphenylethyl ketone* (13), m. p. 169° (Found: halogen, 42·1. $C_{17}H_{13}O_3ClBr_2$ requires halogen, 42·4%); and p-*tolyl* αβ-*dichloro*-β-6-*bromo*-3:4-*methylenedioxyphenylethyl ketone* (14), m. p. 160° (Found: halogen, 36·2. $C_{17}H_{13}O_3Cl_2Br$ requires halogen, 36·3%).

Nuclear Halogenation of Chalkones (1) *and* (2).—The precipitate of (7) obtained when chlorine was passed through a solution of (1) (20 g.) in acetic acid (160 c.c.) dissolved with evolution of hydrogen chloride on continued passage of chlorine (2 mols.) and p-*tolyl* αβ-*dichloro*-β-3-*chloro*-p-*anisylethyl ketone* (15) (16 g.), m. p. 125°, separated after 12 hours (Found: Cl, 29·9. $C_{17}H_{15}O_2Cl_3$ requires Cl, 29·8%). p-*Tolyl* αβ-*dibromo*-β-3-*bromo*-p-*anisylethyl ketone* (16), m. p. 176°, was prepared by the action of bromine (2 mols.) on (1) in hot glacial acetic acid (Found: Br, 48·7. $C_{17}H_{15}O_2Br_3$ requires Br, 48·9%). The ketone (2) similarly yielded p-*tolyl* αβ-*dichloro*-β-6-*chloro*-3:4-*methylenedioxyphenylethyl ketone* (17), m. p. 157° (Found: Cl, 28·6. $C_{17}H_{13}O_3Cl_3$ requires Cl, 28·7%), and p-*tolyl* αβ-*dibromo*-β-6-*bromo*-3:4-*methylenedioxyphenylethyl ketone* (18), m. p. 175° (Found: Br, 47·7. $C_{17}H_{13}O_3Br_3$ requires Br, 47·6%). All the halogen compounds were crystallised from acetic acid or benzene.

Action of Potassium Iodide on the Dihalides.—The position of the nuclear halogen in (15), (16), (17) and (18) is fixed by the fact that, when these compounds are boiled with potassium

iodide (2 mols.) in acetone for 3 hours, iodine separates, and the solutions yield respectively the corresponding chalkones (3), (4), (5) and (6) (mixed m. p. comparison).

Action of Alcohols on the Chalkone Dihalides.—The following β-alkoxy-compounds separated from cooled solutions of the corresponding dihalides in methyl or ethyl alcohol which had been boiled from 1—8 hours, the longer period being necessary with the chloro-compounds: p-*tolyl α-chloro-β-methoxy-β-*p-*anisylethyl ketone* (19), m. p. 107° (Found: Cl, 11·3. $C_{18}H_{19}O_3Cl$ requires Cl, 11·1%); p-*tolyl α-bromo-β-ethoxy-β-*p-*anisylethyl ketone* (20), m. p. 103° (Found: Cl, 11·1. $C_{19}H_{21}O_3Cl$ requires Cl, 10·7%), p-*tolyl α-bromo-β-methoxy-β-*p-*anisylethyl ketone* (21), m. p. 114° (Found: Br, 21·9. $C_{18}H_{19}O_3Br$ requires Br, 22·1%); p-*tolyl α-bromo-β-ethoxy-β-*p-*anisylethyl ketone* (22), m. p. 105° (Found: Br, 21·8. $C_{19}H_{21}O_3Br$ requires Br, 21·2%); p-*tolyl α-chloro-β-methoxy-β-3-chloro-*p-*anisylethyl ketone* (23), m. p. 108° (Found: Cl, 19·9. $C_{18}H_{18}O_3Cl_2$ requires Cl, 20·1%); p-*tolyl α-chloro-β-ethoxy-β-3-chloro-*p-*anisylethyl ketone* (24), m. p. 128° (Found: Cl, 19·0. $C_{19}H_{20}O_3Cl_2$ requires Cl, 19·4%); p-*tolyl α-bromo-β-methoxy-β-3-chloro-*p-*anisylethyl ketone* (25), m. p. 126° (Found: C, 54·4; H, 4·5; halogen, 29·0. $C_{18}H_{18}O_3ClBr$ requires C, 54·4; H, 4·6; halogen, 29·1%); p-*tolyl α-chloro-β-ethoxy-β-3-bromo-*p-*anisylethyl ketone* (26), m. p. 128° (Found: halogen, 27·7. $C_{19}H_{20}O_3ClBr$ requires halogen, 28·1%); p-*tolyl α-bromo-β-methoxy-β-3-bromo-*p-*anisylethyl ketone* (27), m. p. 101° (Found: Br, 35·9. $C_{18}H_{18}O_3Br_2$ requires Br, 36·3%); p-*tolyl α-bromo-β-ethoxy-β-3-bromo-*p-*anisylethyl ketone* (28), m. p. 103° (Found: Br, 34·9. $C_{19}H_{20}O_3Br_2$ requires Br, 35·1%); p-*tolyl α-chloro-β-methoxy-β-3 : 4-methylenedioxyphenylethyl ketone* (29), m. p. 94° (Found: Cl, 10·7. $C_{18}H_{17}O_4Cl$ requires Cl, 10·6%); p-*tolyl α-chloro-β-ethoxy-β-3 : 4-methylenedioxyphenylethyl ketone* (30), m. p. 95° (Found: C, 65·8; H, 5·1; Cl, 10·3. $C_{19}H_{19}O_4Cl$ requires C, 65·8; H, 5·5; Cl, 10·1%); p-*tolyl α-bromo-β-methoxy-β-3 : 4-methylenedioxyphenylethyl ketone* (31), m. p. 120° (Found: Br, 21·1. $C_{18}H_{17}O_4Br$ requires Br, 21·2%); p-*tolyl α-bromo-β-ethoxy-β-3 : 4-methylenedioxyphenylethyl ketone* (32), m. p. 115° (Found: Br, 20·7. $C_{19}H_{19}O_4Br$ requires Br, 20·5%); p-*tolyl α-chloro-β-methoxy-β-6-chloro-3 : 4-methylenedioxyphenylethyl ketone* (33), m. p. 114° (Found: Cl, 19·5 $C_{18}H_{16}O_4Cl_2$ requires Cl, 19·3%); p-*tolyl α-chloro-β-ethoxy-β-6-chloro-3 : 4-methylenedioxyphenylethyl ketone* (34), m. p. 95° (Found: Cl, 18·9. $C_{19}H_{18}O_4Cl_2$ requires Cl, 18·6%); p-*tolyl α-bromo-β-methoxy-β-6-bromo-3 : 4-methylenedioxyphenylethyl ketone* (35), m. p. 121° (Found: Br, 35·4. $C_{18}H_{16}O_4Br_2$ requires Br, 35·1%); and p-*tolyl α-bromo-β-ethoxy-β-6-bromo-3 : 4-methylenedioxyphenylethyl ketone* (36), m. p. 104° (Found: Br, 34·4. $C_{19}H_{18}O_4Br_2$ requires Br, 34·1%).

Action of Hydrobromic Acid on the α-Chloro-β-alkoxy-compounds.—The ketone (20), when kept in contact with concentrated hydrobromic acid for 12 hours, yielded p-*tolyl α-chloro-β-bromo-β-*p-*anisylethyl ketone* (37), m. p. 154° (benzene) (Found: C, 55·6; H, 4·4; halogen, 31·7. $C_{17}H_{16}O_2ClBr$ requires C, 55·5; H, 4·4; halogen, 31·4%). p-*Tolyl α-chloro-β-bromo-β-3-chloro-*p-*anisylethyl ketone* (38), m. p. 157° (benzene) (Found: C, 50·8; H, 3·8; halogen, 37·3. $C_{17}H_{15}O_2Cl_2Br$ requires C, 50·7; H, 3·7; halogen, 37·6%), p-*tolyl α-chloro-β-bromo-β-3-bromo-*p-*anisylethyl ketone* (39), m. p. 161° (carbon tetrachloride) (Found: halogen, 44·0. $C_{17}H_{15}O_2ClBr_2$ requires halogen, 43·8%), p-*tolyl α-chloro-β-bromo-β-3 : 4-methylenedioxyphenylethyl ketone* (40), m. p. 137° (light petroleum) (Found: halogen, 30·5. $C_{17}H_{14}O_3ClBr$ requires halogen, 30·3%), and p-*tolyl α-chloro-β-bromo-β-6-chloro-3 : 4-methylenedioxyphenylethyl ketone* (41), m. p. 165° (light petroleum) (Found: C, 49·0; H, 3·2; halogen, 36·7. $C_{17}H_{13}O_3Cl_2Br$ requires C, 49·0; H, 3·1; halogen, 36·3%), were similarly prepared from (23), (26), (30), and (34) respectively and hydrobromic acid.

Action of Potassium Cyanide on the Dihalides in the Cold.—The compound (10), when shaken for 6 hours with half its weight of potassium cyanide dissolved in cold alcohol, gave the chalkone (2) (mixed m. p. comparison). The corresponding chalkones (4) and (6) were likewise obtained from the halides (16) and (18). The compound (8), similarly treated, gave β-p-*toluoyl-α-*p-*anisylpropionitrile* (42), m. p. 106° (Found: C, 77·3; H, 6·1; N, 5·1. $C_{18}H_{17}O_2N$ requires C, 77·4; H, 6·1; N, 5·0%). On the other hand the filtrate obtained after removal of the solid residue from a mixture of (15) (10 g.), potassium cyanide (3·8 g.), and alcohol (100 c.c.) which had been shaken in the cold for 3 hours gave, on keeping, a precipitate (5·5 g.) of p-*tolyl α : 3-dichloro-4-methoxystyryl ketone* (43), which formed yellow needles, m. p. 115° (Found: Cl, 22·0. $C_{17}H_{14}O_2Cl_2$ requires Cl, 22·1%). Here potassium cyanide acts as a weak alkali.

Action of Potassium Cyanide on the Dihalides in the Warm.—The filtrate obtained after removal in the warm of the solid residue from a mixture of (16) (10 g.), potassium cyanide (3·6 g.) in water (5 c.c.), and alcohol (100 c.c.) which had been heated under reflux for 5 hours gave, on keeping, β-p-*toluoyl-α-3-bromo-*p-*anisylpropionitrile* (44) (4·2 g.), m. p. 135° (Found:

Br, 22·3. $C_{18}H_{14}O_2NBr$ requires Br, 22·4%). The compounds (8), (10), and (18), respectively, gave under similar conditions (42), β-p-*toluoyl-α-3 : 4-methylenedioxyphenylpropionitrile* (45), m. p. 115° (Found : C, 73·7; H, 5·1; N, 5·2. $C_{18}H_{15}O_3N$ requires C, 73·7; H, 5·1; N, 4·8%), and β-p-*toluoyl-α-6-bromo-3 : 4-methylenedioxyphenylpropionitrile* (46), m. p. 149° (Found : Br, 21·4. $C_{18}H_{14}O_3NBr$ requires Br, 21·5%). The nitrile (42), β-p-*toluoyl-α-3-chloro-*p-*anisylpropionitrile* (47), m. p. 144° (Found : Cl, 11·0. $C_{18}H_{16}O_2NCl$ requires Cl, 11·3%), and the nitrile (45) were also obtained by direct addition of hydrogen cyanide to the chalkones (1), (3), and (2) by Hann and Lapworth's method (*loc. cit.*).

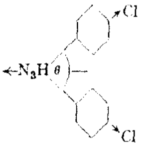
Hydrolysis of the Nitriles.—A mixture of (45) (2·5 g.), 2N-sodium hydroxide (25 c.c.), and alcohol (15 c.c.), which had been heated under reflux at 100° for 8 hours, was filtered, and acidified with hydrochloric acid (1 : 1) to precipitate β-p-*toluoyl-α-3 : 4-methylenedioxyphenylpropionic acid* (48), m. p. 160° (dilute alcohol) (Found : C, 69·2; H, 5·3; equiv., 311·2. $C_{18}H_{16}O_5$ requires C, 69·2; H, 5·1%; equiv., 312), as an oil which afterwards solidified. β-p-*Toluoyl-α-6-bromo-3 : 4-methylenedioxyphenylpropionic acid* (49), m. p. 188° (dilute alcohol) (Found : C, 55·3; H, 3·9; Br, 20·9; equiv., 392·2. $C_{18}H_{15}O_5Br$ requires C, 55·2; H, 3·8; Br, 20·5%; equiv., 391), was similarly obtained from (46). Direct hydrolysis of the crude product obtained by treating (17) with alcoholic potassium cyanide gave a paste, which on precipitation from sodium carbonate solution yielded *p*-toluic acid (mixed m. p. comparison) (Found : C, 70·4; H, 5·9. Calc. : C, 70·6; H, 5·9%).

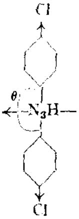
Action of Bases on the Chalkone Dihalides. Preparation of α-Halogenostyryl Ketones.—A solution of sodium methoxide (0·7 g. of sodium) and the compound (7) (10 g.) in methyl alcohol (50 c.c.) was boiled under reflux for 1 hour, filtered while hot from sodium chloride, and cooled; p-*tolyl α-chloro-4-methoxystyryl ketone* (50) (5·5 g.), m. p. 98° (Found : C, 70·9; H, 5·2; Cl, 12·3. $C_{17}H_{15}O_2Cl$ requires C, 71·2; H, 5·2; Cl, 12·4%), separated. This was also obtained (mixed m. p. comparison) by heating (7) with pyridine at the b. p. for 10 seconds, diluting the cooled solution with alcohol, and washing the resulting precipitate with dilute hydrochloric acid; alternatively the cooled pyridine solution was diluted with ether, and the pyridine removed with dilute hydrochloric acid. The compound (19) evolved methyl alcohol at 155° and left (50) as an oil which solidified on keeping. p-*Tolyl α-bromo-4-methoxystyryl ketone* (51), m. p. 102° (Found : C, 61·6; H, 4·6; Br, 24·4. $C_{17}H_{15}O_2Br$ requires C, 61·6; H, 4·5; Br, 24·2%), the ketone (43), p-*tolyl 3-chloro-α-bromo-4-methoxystyryl ketone* (52), m. p. 117° (Found : halogen, 31·7. $C_{17}H_{14}O_2ClBr$ requires halogen, 31·6%), p-*tolyl α-chloro-3-bromo-4-methoxystyryl ketone* (53), m. p. 107° (Found : halogen, 31·5. $C_{17}H_{14}O_2ClBr$ requires halogen, 31·6%), p-*tolyl α : 3-dibromo-4-methoxystyryl ketone* (54), m. p. 114° (Found : Br, 38·9. $C_{17}H_{14}O_2Br_2$ requires Br, 39·0%), p-*tolyl α-chloro-3 : 4-methylenedioxystyryl ketone* (55), m. p. 85° (Found : Cl, 11·9. $C_{17}H_{13}O_3Cl$ requires Cl, 11·7%), p-*tolyl α-bromo-3 : 4-methylenedioxystyryl ketone* (56), m. p. 80° (Found : Br, 22·9. $C_{17}H_{13}O_3Br$ requires Br, 23·2%), p-*tolyl α : 6-dichloro-3 : 4-methylenedioxystyryl ketone* (57), m. p. 114° (Found : Cl, 21·1. $C_{17}H_{12}O_3Cl_2$ requires Cl, 21·2%), p-*tolyl 6-chloro-α-bromo-3 : 4-methylenedioxystyryl ketone* (58), m. p. 130° (Found : halogen, 30·9. $C_{17}H_{12}O_3ClBr$ requires halogen, 30·5%), p-*tolyl α-chloro-6-bromo-3 : 4-methylenedioxystyryl ketone* (59), m. p. 124° (Found : halogen, 30·8. $C_{17}H_{12}O_3ClBr$ requires halogen, 30·5%), and p-*tolyl α : 6-dibromo-3 : 4-methylenedioxystyryl ketone* (60), m. p. 130° (Found : Br, 37·8. $C_{17}H_{12}O_3Br_2$ requires Br, 37·7%), were obtained from the corresponding chalkone halides by the action of sodium methoxide (1 mol.) or of pyridine. The mixed dihalides (37), (38), and (39) with pyridine yielded respectively (50), (43), and (53). The compounds (51), (43), and (54) were also obtained by heating (22), (24), and (28) above the m. p. until evolution of alcohol ceased. All the α-halogenostyryl compounds are yellow.

Action of Bases on the Chalkone Dihalides. Preparation of 1 : 3-*Diketones.*—Addition of water to a mixture of (15) (20 g.), and sodium (3 g.) in methyl alcohol (60 c.c.), which had been heated under reflux for 1 hour, gave an oil; this solidified when the whole was boiled with concentrated hydrochloric acid (10 c.c.) for an hour, and yielded 3-*chloro*-p-*anisoyl*-p-*toluoylmethane* (61) (13 g.), m. p. 135° (Found : Cl, 12·1. $C_{17}H_{15}O_3Cl$ requires Cl, 11·7%). The *copper* salt (62), obtained by heating (61) in alcoholic solution with copper acetate, separated from bromobenzene in green needles, m. p. 258° (Found : Cl, 10·3. $C_{34}H_{28}O_6Cl_2Cu$ requires Cl, 10·7%). 3-*Bromo*-p-*anisoyl*-p-*toluoylmethane* (63), similarly prepared from (16), had m. p. 122° (Found : Br, 23·4. $C_{17}H_{15}O_3Br$ requires Br, 23·1%). 3 : 4-*Methylenedioxybenzoyl*-p-*toluoylmethane* (64), from (9) and (10), had m. p. 114° [Found : C, 72·2; H, 5·1. $C_{17}H_{14}O_4$ requires C, 72·4; H, 4·9%. Found : enol (Meyer, *Annalen*, 1911, **380**, 212) in freshly prepared 0·3% methyl- or ethyl-alcoholic solution, 92·9, 93·5%; in 0·3% ethyl-alcoholic solution which had been kept for 2 days, 100%], and gave a *copper* salt (65), m. p.

that of its parent, *i.e.*, approximately $0{\cdot}9 + 2 \times 0{\cdot}3 = 1{\cdot}5$. Actually its moment is 0·9, which is in better agreement with the second result. An angle of 47½° also appears, on general grounds, to be improbable.

The occurrence of the interaction mentioned above does not disturb the calculation very seriously, for the value of θ is not greatly affected if a different value is taken for the

(I.) 

 (II.)

2(C–Cl) resultant = 1·94 + 0·90; θ = 47½°. 2(C–Cl) resultant = 1·94 − 0·90; θ = 141°.

C–Cl moment; for example, if in the above calculation this were $1{\cdot}55 \pm 0{\cdot}1$, θ would be $140° \, 45' \pm 2° \, 30'$.

If the resultant moment of 4 : 4′-dichlorodiazoaminobenzene is not parallel to the bisector of θ, but is at an angle *A* to this line, θ being approximately 140°, it can be shown that a more accurate value is given by the equation

$$\cos \theta/2 = (1{\cdot}94 \sec A - 0{\cdot}90)/2 \times 1{\cdot}55$$

Then if *A* is as great as 12°, θ becomes 139° 20′. The correction is small, and is of opposite sign to, and of the same order of magnitude as, that for interaction.

Similarly, Bergmann, Engel, and Sandor's value (*loc. cit.*) of 1·42 for *p*-bromoazobenzene being taken as the appropriate C–Br link moment,

$$1{\cdot}88 - 0{\cdot}90 = 2 \times 1{\cdot}42 \cos \theta/2, \text{ whence } \theta = 140°.$$

A reliable confirmatory value could not be obtained from the moment of 4 : 4′-dinitrodiazoaminobenzene, as this substance was too sparingly soluble in benzene.

The difference between the moments of *N*-methyl- and 4 : 4′-dibromo-*N*-methyldiazoaminobenzene corresponds to a similar angle :

$$2{\cdot}52 - 1{\cdot}49 = 2 \times 1{\cdot}42 \cos \theta/2, \text{ and } \theta = 137\tfrac{1}{2}°.$$

The value of θ in both the methylated and the unmethylated compounds may thus be given as 140°, with a probable error of less than 5°.

The moments of 4-bromo- and 4-nitro-diazoaminobenzene are found to be of no service in calculating θ, for the answers obtained depend very largely on the values taken for the C–Br and C–NO_2 link moments; *e.g.*, if the moment of the 4-bromo-derivative were the resultant of a group moment of 0·90 along the bisector of θ and a C–Br link moment of 1·37 or 1·47 at an angle θ/2 to it, θ should satisfy the equation

$$(2{\cdot}00)^2 = (1{\cdot}37)^2 + (0{\cdot}90)^2 + 2 \times 1{\cdot}37 \times 0{\cdot}90 \cos \theta/2, \text{ whence } \theta = 116°;$$

or

$$(2{\cdot}00)^2 = (1{\cdot}47)^2 + (0{\cdot}90)^2 + 2 \times 1{\cdot}47 \times 0{\cdot}90 \cos \theta/2, \text{ whence } \theta = 134°.$$

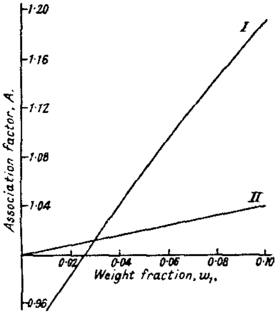
Similarly, if 4·0 or 4·1 is taken for the C–NO_2 link in 4-nitrodiazoaminobenzene,

$$(4{\cdot}77)^2 = (4{\cdot}0)^2 + (0{\cdot}90)^2 + 2 \times 4{\cdot}0 \times 0{\cdot}90 \cos \theta/2, \text{ whence } \theta = 67°;$$

or

$$(4{\cdot}77)^2 = (4{\cdot}1)^2 + (0{\cdot}90)^2 + 2 \times 4{\cdot}1 \times 0{\cdot}90 \cos \theta/2, \text{ whence } \theta = 91°.$$

(2) *Association of Diazoaminobenzene in Benzene Solution.*—The slight decrease in the polarisation of diazoaminobenzene with concentration is qualitatively in agreement with Hunter's observations (this vol., p. 320) of the molecular weights of diazoamino-compounds in benzene solution. He finds that association occurs as the solutions become more concentrated, and suggests the formation of a double molecule by resonance. He puts forward two possible forms, the first of which would be highly polar, and its formation would correspond to an increase in the polarisation, whilst the second form, which he regards as the more probable, would apparently have zero moment. His results, expressed as the association factor A, the ratio of the apparent to the true molecular weight, are shown in curve I. The dimeric form being assumed to have zero moment, the same factor has been calculated from the polarisation measurements (curve II): I is clearly much steeper than II. The divergence may be attributed to the incorrectness of the assumption that association consists entirely of the formation of non-polar double molecules.



Experimental.

Preparation of Materials.—*N*-Methyldiazoaminobenzene was made from methylaniline and diazotised aniline; being an unstable liquid, it was purified by dissolving it in alcohol and cooling the solution in solid carbon dioxide–alcohol, whereupon it separated as a pale yellow sticky material. The most likely impurity was then methylaniline; to test the effect of this, the polarisation of a sample containing 10% was measured and found to be practically unchanged. 4 : 4′-Dibromo-*N*-methyldiazoaminobenzene, previously obtained only by direct methylation, was readily prepared from *p*-bromomethylaniline and diazotised aniline.

Diazoaminobenzene and its 4 : 4′-dimethyl-derivative were obtained in a pure state in one operation by a slight modification of Meunier's method (*Comp. rend.*, 1903, **137**, 1264; cf. Earl, *Proc. Roy. Soc. N.S.W.*, 1929, **53**, 89; 1930, **54**, 96). The base (0·1 g.-mol.), sodium nitrite (0·2 g.-mol.), water (40 c.c.), and alcohol (40 c.c.) were treated with carbon dioxide for about 4 hours. Filtration gave the diazoamino-compounds as pure yellow needles, m. p. 99° and 117·5—118° respectively. The latter m. p. is 1—1·5° greater than the highest previously recorded (Witt, *Ber.*, 1877, **10**, 1309).

Measurements, and Calculation of Results.—The dielectric constant and density of solutions of many substances vary linearly with concentration and can be expressed by the equations $\varepsilon = \varepsilon_2(1 + \alpha f_1)$ and $d = d_2(1 + \beta f_1)$, where the suffixes 1 and 2 denote the solute and solvent respectively and f is the mol.-fraction. Hedestrand (*Z. physikal. Chem.*, 1929, *B*, **2**, 428) has shown that the molecular polarisation at infinite dilution can be calculated from α and β thus,

$$P_{1_\infty} = A(M_1 - \beta M_2) + B\alpha\varepsilon_2$$

where A and B are constant. Fairly concentrated solutions can be used, and α and β determined accurately, whereas graphical extrapolation requires very dilute solutions from which P_1 cannot be found accurately.

A similar expression is obtained if the weight fraction w_1 and the specific polarisations p_1 and p_2 are used, and this involves less work in the calculation. Let $\varepsilon = \varepsilon_2(1 + \alpha w_1)$ and $d = d_2(1 + \beta w_1)$; then

$$\begin{aligned} p_1 &= (p_{12} - p_2 w_2)/w_1 \\ &= \frac{\varepsilon - 1}{\varepsilon + 2}\cdot\frac{1}{d} + \frac{w_2}{w_1}\left(\frac{\varepsilon - 1}{\varepsilon + 2}\cdot\frac{1}{d} - \frac{\varepsilon_2 - 1}{\varepsilon_2 + 2}\cdot\frac{1}{d_2}\right) \\ &= \frac{\varepsilon - 1}{\varepsilon + 2}\cdot\frac{1}{d} + \frac{w_2}{d}\cdot\frac{3\alpha\varepsilon_2 - \beta(\varepsilon_2 - 1)[\varepsilon_2(1 + \alpha w_1) + 2]}{[\varepsilon_2(1 + \alpha w_1) + 2][\varepsilon_2 + 2]} \end{aligned}$$

w_1.	$\epsilon^{1200}_{25°}$.	$d^{25°}_{4°}$.	p_{12}.	P_1.	$\alpha\epsilon_2$.	β.	$n^{25°}_D$.	r_{12}.	$[R_L]_D$.
0	2·2725	0·87378	0·34086	—	—	—	1·49724	0·33503	—
				Diazoaminobenzene.					
0·00351	2·2759	0·87451	0·34121	86·9	0·97	0·238	1·49795	0·33494	72·7
0·01188	2·2837	0·87624	0·34200	86·1	0·94	0·237	1·49948	0·33536	71·5
0·02589	2·2970	0·87923	0·34330	85·7	0·95	0·241	1·50203	0·33566	70·7
0·02900	2·3001	0·87992	0·34360	85·7	0·95	0·243	1·50263	0·33574	70·7
0·03587	2·3057	0·88126	0·34411	85·1	0·926	0·239	1·50388	0·33594	70·9
0·04187	2·3117	0·88257	0·34470	85·3	0·936	0·240	1·50492	0·33602	70·7
0·07100	2·3398	0·88880	0·34735	85·1	0·948	0·243	1·51012	0·33657	70·3
0·08486	2·3514	0·89182	0·34824	84·3	0·930	0·243	1·51273	0·33687	70·3
				4 : 4′-Dimethyldiazoaminobenzene.					
0·00774	2·2788	0·87518	0·34149	95	0·81	0·207	—	—	—
0·00826	2·2797	0·87523	0·34164	98	0·87	0·201	1·49859	0·33524	81·0
0·00929	2·2806	0·87543	0·34173	98	0·87	0·203	—	—	—
0·01663	2·2872	0·87677	0·34244	98	0·88	0·206	1·49996	0·33543	80·8
0·02000	2·2906	0·87729	0·34287	99	0·90	0·201	—	—	—
0·03009	2·2993	0·87902	0·34381	99	0·89	0·199	1·50228	0·33589	81·7
				4 : 4′-Dichlorodiazoaminobenzene.					
0·00460	2·2829	0·87518	0·34226	172	2·26	0·348	1·49803	0·33494	83·9
0·00739	2·2884	0·87608	0·34294	165	2·15	0·353	1·49843	0·33483	81·9
0·00995	2·2935	0·87687	0·34357	163	2·11	0·352	1·49891	0·33480	83·0
0·01518	2·3020	0·87849	0·34451	151	1·95	0·351	1·49967	0·33461	81·7
0·02148	2·3146	—	—	—	1·96	—	—	—	—
0·02470	2·3200	—	—	—	2·00	—	—	—	—
				4 : 4′-Dibromodiazoaminobenzene.					
0·00261	2·2757	0·87490	0·34102	143	1·23	0·491	1·49762	0·33482	90·4
0·00430	2·2794	0·87566	0·34142	167	1·60	0·500	1·49787	0·33467	89·1
0·00779	2·2838	0·87722	0·34163	156	1·45	0·505	1·49841	0·33438	89·1
0·01042	2·2888	—	—	—	1·56	—	—	—	—
0·01487	2·2949	0·88035	0·34247	159	1·51	0·505	1·49939	0·33375	88·4
0·02139	2·3042	—	—	—	1·48	—	—	—	—
				4-Bromodiazoaminobenzene.					
0·00857	2·2892	0·87694	0·34275	155	1·95	0·422	1·49865	0·33462	79·2
0·01588	2·3050	0·87941	0·34470	161	2·05	0·406	1·49978	0·33432	80·0
0·03571	2·3468	0·88681	0·34938	160	2·08	0·418	1·50291	0·33329	78·9
0·04634	2·3700	0·89053	0·35093	154	2·10	0·413	1·50474	0·33292	79·9
0·05360	2·3850	0·89335	0·35356	160	2·10	0·418	1·50582	0·33247	79·3
				4-Nitrodiazoaminobenzene.					
0·00265	2·3030	0·87455	0·34625	574	11·5	0·332	1·49776	0·33503	92
0·00414	2·3191	0·87501	0·34904	564	11·3	0·340	1·49808	0·33504	93
0·00462	2·3240	0·87515	0·34988	555	11·1	0·339	1·49818	0·33504	93
0·00566	2·3358	0·87541	0·35193	556	11·2	0·331	1·49846	0·33510	96
0·00583	2·3362	0·87548	0·35198	544	10·9	0·334	1·49842	0·33505	93
				N-*Methyldiazoaminobenzene.*					
0·00789	2·2859	0·87528	0·34278	123	1·70	0·217	1·49856	0·33521	75·5
0·01525	2·2970	0·87672	0·34428	119	1·61	0·221	1·49970	0·33530	74·5
0·02245	2·3097	0·87815	0·34606	121	1·657	0·223	1·50089	0·33543	74·5
0·03281	2·3260	0·88022	0·34823	119	1·631	0·224	1·50264	0·33563	74·7
0·04623	2·3463	0·88265	0·35086	118	1·596	0·224	—	—	—
				*4 : 4′-Dibromo-*N-*methyldiazoaminobenzene.*					
0·00571	2·2858	0·87619	0·34241	226	2·33	0·483	—	—	—
0·00745	2·2899	0·87692	0·34289	227	2·34	0·482	1·49825	0·33440	92·3
0·01443	2·3048	0·87990	0·34446	218	2·24	0·485	1·49919	0·33380	92·3
0·02133	2·3205	0·88282	0·34620	218	2·25	0·485	1·50021	0·33328	93·4

Diazoaminobenzene derivative.	M.	Mean values of $\alpha\epsilon_2$.	Mean values of β.	P_∞.	$[R_L]_D$.	μ.
(Unsubstituted)	197	0·940	0·241	85·8	70·6	0·90 ± 0·02
4 : 4′-Dimethyl-	225	0·87	0·203	98·1	81·2	0·90 ± 0·04
4 : 4′-Dichloro-	266	2·04	0·351	161	83	1·94 ± 0·04
4 : 4′-Dibromo-	355	1·52	0·503	162	89	1·88 ± 0·04
4-Bromo-	276	2·00	0·415	162	79·5	2·00 ± 0·04
4-Nitro-	242	11·2	0·335	565	93	4·77 ± 0·06
N-Methyl-	211	1·64	0·223	120·9	74·8	1·49 ± 0·03
4 : 4′-Dibromo-*N*-methyl-	369	2·29	0·484	224	93	2·52 ± 0·04

Taking the limit, as $w_1 \rightarrow 0$,

$$\begin{aligned} p_\infty &= \frac{\varepsilon_2 - 1}{\varepsilon_2 + 2} \cdot \frac{1}{d_2} + \frac{3\alpha\varepsilon_2 - \beta(\varepsilon_2 - 1)(\varepsilon_2 + 2)}{d_2(\varepsilon_2 + 2)^2} \\ &= \frac{\varepsilon_2 - 1}{\varepsilon_2 + 2} \cdot \frac{1}{d_2}(1 - \beta) + \frac{3\alpha\varepsilon_2}{d_2(\varepsilon_2 + 2)^2} \\ &= p_2(1 - \beta) + c\alpha\varepsilon_2 \qquad (1) \end{aligned}$$

where p_2 and c are constants for the solvent and were equal to 0·34086 and 0·18809 respectively for the benzene used.

Density and dielectric constant were plotted against w_1 for the solutions of each substance and found to give good straight lines; $\alpha\varepsilon_2$ and β were, therefore, obtained and p_∞ calculated by means of the equation (1). The data are tabulated on page 1808.

Association of Diazoaminobenzene.—If a substance 'a' is partly associated in solution, let w_a, w_{a_1}, and w_{a_2} be the weight fractions and ${}_0p_a$, ${}_0p_{a_1}$, and ${}_0p_{a_2}$ the specific orientation polarisations of the mixture and of the mono- and the di-meric form respectively, and let $\gamma w_a = w_{a_2}$.

Then $${}_0p_a w_a = {}_0p_{a_1} w_{a_1} + {}_0p_{a_2} w_{a_2}$$

Therefore $${}_0p_a = {}_0p_{a_1}(1 - \gamma) + {}_0p_{a_2}\gamma$$

and $$\gamma = ({}_0p_{a_1} - {}_0p_a)/({}_0p_{a_1} - {}_0p_{a_2})$$

If ${}_0p_{a_2} = 0$ and if r_a is the specific refraction of a,

$$\gamma = (p_{a_1} - p_a)/(p_{a_1} - r_a) \qquad (2)$$

It is easily seen that the association factor A is equal to $2/(2 - \gamma)$.

The measurements show that the specific refraction of diazoaminobenzene is 0·3585. By assuming $\alpha\varepsilon_2 = 0{\cdot}940$ and $\beta = 0{\cdot}241$, values of d and ε have been calculated at various concentrations, from which the specific polarisation has been obtained. Formula (2) has been used to find A in each case, p_∞ being taken as 0·4355, as calculated from equation (1). The results are expressed by curve II in the diagram.

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Note (*added September 27th*, 1937).—Since the preceding results were obtained, it has been shown (Hartley, *Nature*, 1937, **140**, 281) that azobenzene is partly converted in solution into the *cis*-form when exposed to daylight. Measurements of the dipole moments of the pure *cis*-, pure *trans*-, and equilibrated azobenzenes have been carried out by one of us and reported briefly in the above reference. Illumination causes a considerable increase in the dielectric constants of solutions of the stable *trans*-form. It was, therefore, considered important to discover whether errors have been introduced into the measurement of the dielectric constant of solutions of the diazoamino-compounds owing to their being allowed to stand in ordinary white glass vessels. The dielectric constants (ε_{I}) of solutions of diazoaminobenzene and 4 : 4'-dibromo-*N*-methyldiazoaminobenzene which have been kept in brown bottles have been compared with those (ε_{II}) of solutions which have been exposed to bright sunlight for about 3 hours. As the differences (see below) are small, the results tabulated above are considered to be satisfactory.

Diazoaminobenzene.			4 : 4'-*Dibromo*-N-*methyldiazoaminobenzene.*		
w_1.	ε_{I}.	ε_{II}.	w_1.	ε_{I}.	ε_{II}.
0·01888	2·2887	2·2891	0·01614	2·3083	2·3079
0·04912	2·3190	2·3198	0·02256	2·3228	2·3230

380. *The Labile Nature of the Halogen Atom in Organic Compounds. Part XV. The Action of Hydrazine on Bromomalonic Esters.*

By H. P. Gallus and A. Killen Macbeth.

The positive character of the halogen atom in bromomalonic esters expresses itself in the oxidation of hydrazine hydrate, and measurement of the nitrogen liberated provides a method for determining the extent to which the reaction proceeds. The rate of reaction is greatly decreased in the case of the higher esters, those of the primary alcohols requiring up to 15 minutes for liberation of the final volume of nitrogen. The time is still greater with esters of the secondary alcohols, and the oxidation is not quantitative.

The isolation of the *hydrazone* of mesoxalhydrazide when *iso*butyl and *iso*amyl dibromomalonates are treated with hydrazine hydrate indicates that, although hydrolysis involving the replacement of bromine by hydrogen is the main reaction, the alternative course in which the halogen is replaced by hydroxyl is also followed to some extent.

In previous parts of this series it was shown that the halogen atom in compounds such as the halogenated derivatives of nitroparaffins, malonic esters, and certain 1 : 3-diketo-compounds presented marked differences in reactivity from that in, *e. g.*, picryl chloride, acyl halides, and sulphonyl chlorides. In the former type of compound, alternate polarity effects, with the negative oxygens as key atoms, would lead to an induced positive effect on the halogen atoms. The reactivity of such atoms expresses itself in the oxidation of hydrazine hydrate, and the reaction may be followed quantitatively by measurement of the liberated nitrogen, a behaviour which readily differentiates the negative halogen of acyl halides and other compounds, in which hydrazide formation, without oxidation, occurs.

A corollary to the induced positive effect is a difference in reactivity between (1) chlorine and bromine in similarly constituted compounds (Macbeth and Traill, J., 1925, **127**, 1119) and (2) the same halogen in compounds of diverse structure (Macbeth and co-workers, J., 1922, **121**, 1120, 2176; 1923, **123**, 1129; 1926, 1248).

The reduction of the bromomalonic esters by hydrazine is expressed in the following equations, which do not, however, take into account hydrazide formation at the ester groups :

$$CBr_2(CO_2R)_2 + NH_2{\cdot}NH_2 = CH_2(CO_2R)_2 + N_2 + 2HBr$$
$$2CHBr(CO_2R)_2 + NH_2{\cdot}NH_2 = 2CH_2(CO_2R)_2 + N_2 + 2HBr$$

Hirst and Macbeth (J., 1922, **121**, 904) found that, whereas ethyl bromomethylmalonate reacted completely with hydrazine hydrate in a few minutes at laboratory temperature, there was a remarkable decrease in the rate of reaction with the higher homologues; and in these the theoretical amount of nitrogen for complete reduction was not liberated. It was suggested that the low results might be due to the presence of dialkyl-substituted malonates (cf. Fischer, *Ber.*, 1906, **39**, 351), and that the decrease in the rate of reaction might be attributed to steric effects of the substituents. A series of bromo- and dibromo-malonic esters, in which the ester groups are varied, has now been examined. A decrease in the rate of reaction and in the yield of nitrogen is found as the complexity of the ester groups increases; *e.g.*, under the experimental conditions, the bromomalonates behave as follows : the methyl ester gives off the theoretical amount of nitrogen in about 1·75 minutes, the esters of all other primary alcohols require 5—15 minutes, but the volume of nitrogen is somewhat deficient, and those of secondary alcohols require at least 50 minutes and give off much less gas.

Hydrolysis of halogen compounds may follow either of two courses, the halogen being replaced by hydrogen and the solution acquiring oxidising properties, or the halogen being replaced by hydroxyl, and it is probable that cases in which a deficiency of nitrogen is liberated may be accounted for by the occurrence of the second type of reaction to some

extent. This, in the case of a dibromomalonic ester, would lead to the formation of mesoxalic acid, which would be isolated as the *hydrazone* of *mesoxalhydrazide*, and we have actually obtained this hydrazone from the reaction of the *iso*amyl and the *iso*butyl ester with hydrazine hydrate in alcoholic solution. Moreover, we have confirmed the work of Ruhemann and Orton (J., 1895, **67**, 1003), who similarly obtained the hydrazone of mesoxalamide from hydrazine hydrate and dibromomalonamide. Whether or not the course of the former reaction is influenced by the ease of conversion of a particular ester into the hydrazide as a first step cannot yet be answered, but evidence on this point is being sought.

EXPERIMENTAL.

Preparation of Malonic Esters.—These were prepared either (i) by the simultaneous hydrolysis and esterification of sodium cyanoacetate in the presence of the desired alcohol and sulphuric acid, or (ii) by the direct esterification of malonic acid in the presence of excess of alcohol to ensure the formation of the di-ester. In the former method, olefin formation was reduced by adding the sulphuric acid drop by drop during refluxing; and with the same object in view the acid was added in two portions in direct esterification, one-half at the beginning of the reaction and the remainder some 3 hours later when, in the case of the higher alcohols, the liquid showed separation into two layers—with the lower alcohols, on account of their solubilities, such separation does not occur. By this procedure increased yields were obtained, *sec.*-octyl, *cyclo*hexyl, and 2- and 3-methyl*cyclo*hexyl alcohols giving ester in yields of 94, 59, 74, and 69% instead of 70, 44, 60, and 60% respectively. The following malonates were prepared: *n*-Propyl, b. p. 223—225°; *n*-butyl, b. p. 130—131°/12 mm.; *n*-amyl, b. p. 130°/6 mm. (Found: C, 63·8; H, 9·8. Calc.: C, 63·9; H, 9·9%); *n-octyl*, b. p. 176—177°/6 mm. (Found: C, 69·4; H, 11·1. $C_{19}H_{36}O_4$ requires C, 69·4; H, 11·05%); *iso*propyl, b. p. 102°/23 mm. (Found: C, 57·1; H, 8·5. Calc.: C, 57·4; H, 8·6%); *iso*butyl, b. p. 129°/21 mm. (Found: C, 60·6; H, 9·2. Calc.: C, 61·1; H, 9·3%); *iso*amyl, b. p. 144—146°/12 mm.; *sec.*-octyl, b. p. 168—169°/4 mm.; cyclo*hexyl*, b. p. 173°/10 mm. (Found: C, 67·0; H, 8·95. $C_{15}H_{24}O_4$ requires C, 67·2; H, 9·0%); 2-*methyl*cyclo*hexyl*, b. p. 172—173°/10 mm. (Found: C, 68·5; H, 9·5. $C_{17}H_{28}O_4$ requires C, 68·9; H, 9·5%); 3-*methyl*cyclo*hexyl*, b. p. 178°/13 mm. (Found: C, 68·7; H, 9·6%); 4-*methyl*cyclo*hexyl*, b. p. 168°/10 mm. (Found: C, 68·5; H, 9·6%).

Method (i) proved unsatisfactory for the preparation of the *cyclo*hexyl and methyl*cyclo*hexyl esters. Attempts to prepare *tert.*-butyl malonate by this method or by direct esterification using hydrogen chloride or sulphuric acid as catalyst were unsuccessful. Hydrogen chloride was also unsatisfactory in the preparation of *iso*propyl malonate, the yield being only some 22%, and considerable quantities of β-chloropropane being formed.

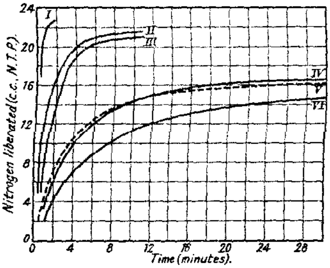
Preparation of Bromomalonic Esters.—The bromo-esters were prepared by the dropwise addition of excess of bromine to the previously warmed ester; the reaction proceeded in diffuse daylight, but was completed in the case of the dibromo-esters in direct sunlight. The mixture was then heated on a water-bath (to remove further hydrogen bromide), cooled, and washed successively with water, dilute sodium carbonate solution, and water. After drying, the product was fractionated. The following bromo-esters were prepared: Methyl bromomalonate, b. p. 110—112°/15 mm.; methyl dibromomalonate, m. p. 65° from light petroleum; *n*-propyl bromomalonate, b. p. 110—112°/8 mm. (Found: Br, 30·0. Calc.: Br, 29·9%); *n*-propyl dibromomalonate, b. p. 118°/6 mm. (Found: Br, 46·1. Calc.: Br, 46·2%); *iso*propyl bromomalonate, b. p. 86°/4 mm. (Found: Br, 29·4%); *iso*propyl dibromomalonate, b. p. 104°/6 mm. (Found: Br, 46·0%); n-*butyl bromomalonate*, b. p. 135—136°/10 mm. (Found: Br, 27·6. $C_{11}H_{19}O_4Br$ requires Br, 27·1%); n-*butyl dibromomalonate*, b. p. 147°/10 mm. (Found: Br, 42·6. $C_{11}H_{18}O_4Br_2$ requires Br, 42·8%); iso*butyl bromomalonate*, b. p. 124—126°/12 mm. (Found: Br, 27·25%); iso*butyl dibromomalonate*, b. p. 138°/10 mm. (Found: Br, 42·6%); n-*amyl bromomalonate*, b. p. 144°/6 mm. (Found: Br, 24·2. $C_{13}H_{23}O_4Br$ requires Br, 24·8%); iso*amyl bromomalonate*, b. p. 146—148°/11 mm. (Found: Br, 24·6%); iso*amyl dibromomalonate*, b. p. 142—143°/4 mm. (Found: Br, 38·7. $C_{13}H_{22}O_4Br_2$ requires Br, 39·8%); sec.-*octyl bromomalonate*, b. p. 169—170°/4 mm. (Found: Br, 19·7. $C_{19}H_{35}O_4Br$ requires Br, 19·7%); cyclo*hexyl bromomalonate*, b. p. 167°/4 mm. (Found: Br, 22·6. $C_{15}H_{23}O_4Br$ requires Br, 23·0%). In 2-, 3-, and 4-methyl*cyclo*hexyl bromomalonates, b. p. 176°/6 mm., 182°/6 mm., and 180—181°/4 mm., respectively, the bromine found was more than 1% lower than the 21·3% required.

Action of Hydrazine Hydrate.—The estimations of nitrogen liberated by the action of the bromo-esters on hydrazine hydrate (50% solution) were carried out in a van Slyke nitrometer.

0·01 G.-mol. of the monobromo-esters or 0·005 g.-mol. of the dibromo-esters was made up to 25 c.c. with absolute alcohol; 5 c.c. of this solution were washed into the reaction vessel with 10 c.c. of absolute alcohol, and vigorous shaking by an electric motor started. The shaking was temporarily stopped by braking whilst 2 c.c. of hydrazine hydrate (50%) were run in from the burette. This ensured the immediate vigorous shaking found necessary for concordant results, which were reproducible within 0·5—1%. The nitrogen liberated was collected over absolute alcohol. The final volumes, after allowance for vapour tension and reduction to *N.T.P.*, are shown above. Complete reduction requires the liberation of 22·4 c.c. of nitrogen at 0° and 760 mm.

	Bromo-malonates.	N_2 (c.c., *N.T.P.*).	Temp.	Time of reaction, mins.
Primary.	Methyl	22·35	23°	1·75
	n-Propyl	20·5	23	7
	n-Butyl	20·9	23	6·5
	n-Amyl	19·9	13	13·5
	n-Octyl	17·15	20	12
	*iso*Butyl	20·7	23	11
	*iso*Amyl	21·25	23	11
Secondary.	*iso*Propyl	16·7	23	65
	sec.-Octyl	15·8	23	75
	*cyclo*Hexyl	16·05	23	50
	2-Methyl*cyclo*-hexyl	14·5	14	120
	3-Methyl*cyclo*-hexyl	14·7	19	60
	4-Methyl*cyclo*-hexyl	15·7	16	150

Dibromo-malonates.	N_2 (c.c., *N.T.P.*).	Temp.	Time of reaction, mins.
Methyl	23·0	23°	2
Propyl	21·2	15	9
Butyl	22·0	17	6·5
*iso*Butyl	21·6	17	9·5
*iso*Amyl	20·5	20	9
*iso*Propyl	17·3	20	60



Reaction of Bromomalonic Esters with Hydrazine Hydrate at 23°.

I. *Methyl ester*; II. iso*Amyl ester*; III. iso*Butyl ester*; IV. iso*Propyl ester*; V. cyclo*Hexyl ester*; VI. sec-*Octyl ester.*

The above figures show that in all the cases examined other than the simple methyl ester, the nitrogen evolved falls somewhat short of the amount required for complete reduction, and the time of reaction also increases. *This is especially marked with the* esters of secondary alcohols. The progressive liberation of nitrogen at 23° was examined, and typical results are recorded in the graphs. These also show the difference between bromo-esters derived from primary and from secondary alcohols.

Hydrazone of Mesoxalhydrazide.—An excess of hydrazine hydrate (50%), when added to an alcoholic solution of *iso*butyl dibromomalonate, caused an energetic exothermic reaction to take place, nitrogen being freely evolved. When the liberation of gas ceased, the mixture was heated for a short time on the water-bath. Silky white needles separated on cooling, and when twice recrystallised from hot water had m. p. 187° (Found: N, 52·8. $C_3H_8O_2N_6$ requires N, 52·2%); a similar product (m. p. and mixed m. p.) was obtained from *iso*amyl dibromomalonate. It is evidently the ***hydrazone*** of ***mesoxalhydrazide***, and its isolation shows that to some extent the action of hydrazine hydrate on bromomalonic esters follows a course other than reduction.

Johnson Chemical Laboratories, University of Adelaide. [*Received, October 4th*, 1937.]

381. *Monolayers of Porphyrins and Related Compounds.*

By A. E. Alexander.

A number of porphyrins and closely related compounds, some containing a central co-ordinated metal atom (chlorophyll-*a* and -*b*, hæmin, magnesium naphthalocyanine, magnesium and iron phthalocyanines), and some without (protoporphyrin, bilirubin, mesoporphyrin dimethyl ester, and hæmatoporphyrin), have been examined in the form of monolayers on aqueous substrates. With the exception of the chlorophylls and hæmatoporphyrin, the compounds formed very unstable solid-condensed films with the conjugated ring systems vertically orientated and close-packed. Owing to the phytol side chains, the chlorophylls gave liquid-expanded films which could be condensed by increase of pressure to the close-packed form with the dihydroporphin rings vertically orientated. The hæmatoporphyrin molecule was unique in that it lay flat on the surface and formed a vapour-expanded type of film.

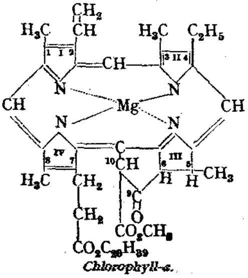
Solutions of all these compounds were intensely coloured, and with the metallic phthalocyanines, particularly magnesium naphthalocyanine, the colour was still visible in the monolayer.

Owing to the biological importance of substances containing the porphin and other similar ring structures, it seemed desirable to examine the nature and properties of such compounds when orientated as monolayers on aqueous substrates. Those examined were: chlorophyll (*a* and *b*), hæmin, magnesium naphthalocyanine, magnesium and iron phthalocyanines, protoporphyrin, bilirubin, mesoporphyrin dimethyl ester, and hæmatoporphyrin. With the exception of bilirubin, which is an open-chain compound, they all possess a fully conjugated ring system of the porphin or closely related phthalocyanine type, the last four differing from the others in having no co-ordinated metal atom at the centre of this system. The metal-containing compounds were originally investigated by Hughes (*Proc. Roy. Soc.*, *A*, 1936, **155**, 710).

Experimental.

The films were examined by the usual methods for surface pressures and surface potentials, and in addition by the dark-field ultramicroscopic method of Zocher and Stiebel (*Z. physikal. Chem.*, 1930, *A*, **147**, 401) in cases of doubtful homogeneity.

Chlorophyll-a *and* -b.—These gave the most stable films of all the compounds examined. The *F–A* and ΔV–*A* curves for films on a phosphate buffer of p_H 7·3 at room temperature are shown in the figure. Both forms gave easily compressible liquid-expanded films, differing but slightly in the limiting area (132 and 137 A.^{2} respectively). The areas since found by Sjoerdsma (*Nature*, 1936, **138**, 405) and by Hanson (*Proc. K. Akad. Wetensch. Amsterdam*, 1937, **40**, 281) agree well with these. The surface potentials were rather different, the range being 305—385 mv. for the *a* form and 250—300 mv. for the *b*. Since the latter contains one oxygen atom more than the former (and therefore an extra polar group), the lower moment found for the *b*-form would indicate that the position of this extra polar group is such that its moment acts in the opposite sense to the other polar groups in the molecule. In the formulæ proposed by Fischer (*Chem. Rev.*, 1937, **20**, 41) the *b*- differs from the *a*-form only in that the methyl group in position 3 has been replaced by a formyl group. Since it is extremely probable that the molecules are orientated in the surface with the ketonic and the two ester groups as the main anchorage, the moment of the formyl group which is attached to the opposite side of the molecule would act in opposition to these, thus reducing the apparent moment. These results from the films are thus seen to be in accord with Fischer's proposed structures (*loc. cit.*).



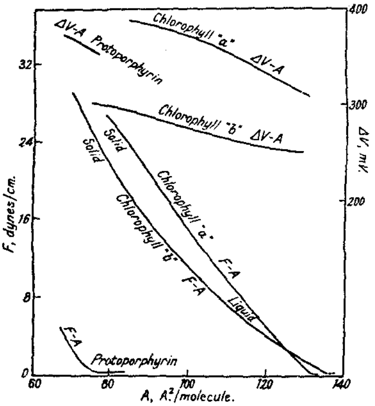
Chlorophyll-a.

The difference between these liquid-expanded films and the condensed films given by the other porphin derivatives must be due to the phytol side chains, which would tend to lie on the surface and so expand the film. On compression, these phytol chains would be removed from

the surface, and the change from liquid to solid at areas of about 90—80 A.[2] would indicate the formation of a close-packed layer of vertically orientated dihydroporphin rings. Evidence for this type of packing is available from a study of films of hæmin and protoporphyrin (see below).

On alkaline solutions the films were stable, but for those of p_H <6 a sharp rise in the surface potential occurred, probably owing to the elimination of magnesium from the molecule. A slow fall in potential of some 50—80 mv. took place with the *b*-form over about 20 minutes. This fall was arrested by the presence of 0·5% of quinol in the substrate, suggesting that it was due to autoxidation.

Examination of the films at large areas by means of the dark-field ultramicroscope showed them to be homogeneous. On compression to the solid state, break lines appeared in the film with no previous point-structure and no fluorescence (cf. the phthalocyanines below).



Hæmin.—The solution for spreading purposes was made up in benzene–pyridine (*ca.* 4 : 1 by vol.). On a phosphate buffer, p_H 7·3, at room temperature, the films obtained were solid and unstable, collapsing very readily on compression at an area of about 70 A.[2]. If the hæmin rings were lying flat on the surface, the area per molecule would be approx. 125 A.[2], and if vertically close-packed, about 68 A.[2]. The proximity of the limiting area to the latter figure showed that the molecules were close-packed vertically, owing to the much stronger hydrophilic nature of the carboxyl than of the vinyl groups. The surface potentials showed that the films were never really homogeneous, the value of ΔV at the limiting area being about 500 mv.

Protoporphyrin, Bilirubin, Mesoporphyrin Dimethyl Ester, and Hæmatoporphyrin.—Solutions were made up by warming the solid with pyridine (*ca.* 1 c.c./mg.) and then diluting with benzene to a suitable volume : unless this procedure was followed, there was a tendency for the solid to be precipitated on standing. A preliminary examination with the dark-field ultramicroscope showed that spreading occurred, but that the films collapsed very readily on compression.

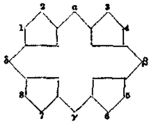
Protoporphyrin (*i.e.*, hæmin minus FeCl) gave the most stable films of these four compounds, although even in this case there was always a quite rapid collapse in the condensed state. The figure gives the *F–A* and ΔV*–A* curves for films on N/100-sulphuric acid at 20°. The films were inhomogeneous at large areas, but formed homogeneous films of the solid-condensed type at areas less than about 76 A.[2]. With increasing p_H the surface potential decreased owing to ionisation of the carboxyl groups. A comparison of the surface potentials of this compound and of hæmin at the same area showed that the latter was the higher by some 350 mv. both at p_H 2 and at p_H 7·8, which must be due to the central co-ordinated metal atom. The area for the solid-condensed films showed that the molecules were orientated vertically in a similar manner to those of hæmin. On these substrates there was no evidence for the molecules ever lying flat—the cohesion between the molecules evidently being greater than the adhesion to the water. It was thought that by spreading on bromine-water or permanganate solutions the adhesion of the vinyl groups would be increased sufficiently to indicate this second limiting area. No effect was observed with bromine-water, but when N/100-sulphuric acid containing 0·5% of potassium permanganate was used as substrate and the film allowed to remain spread at large areas for about 15 minutes, a pronounced effect was observed on the film characteristics. The first definite sign of surface pressure occurred at about 120 A.[2], and on compression the film condensed to a liquid and not a solid film as before. This, in conjunction with the results for hæmatoporphyrin given below, suggests that on permanganate solutions at any rate the molecules do lie flat at the largest areas.

Bilirubin differs from the other compounds in not containing the complete porphin nucleus, since one of the $=CH-$ links has been removed. It formed extremely unstable films of the weak solid or viscous liquid type. On N/100-sulphuric acid at room temperature, the limiting area (*i.e.*, the area at which the first sign of pressure was noted) was about 140 A.[2] at a surface potential of approximately 145 mv. The fission of the porphyrin nucleus would explain the much greater area occupied as compared with the other compounds.

Mesoporphyrin dimethyl ester resembled protoporphyrin closely, giving a solid-condensed film of limiting area about 75 A.[2], and a surface potential of about 425 mv. (at p_H 2), although the films were much less stable owing to the less polar nature of the molecule.

Hæmatoporphyrin only differs from protoporphyrin in possessing secondary alcoholic groups $-CH(OH)\cdot CH_3$ instead of the vinyl groups $-CH=CH_2$. This would increase the polarity of the molecule considerably, and owing to the more symmetrical distribution of the polar groups around the porphin nucleus as compared with protoporphyrin, it would be expected that the molecules would lie flat on the water surface. Actually, this was found to be so. The films were spread from an alcohol–benzene solution of the hydrochloride, and were found to be of the vapour-expanded type, remaining homogeneous out to areas of over 400 A.[2] (p_H 2 and 7·8). Compression gave a liquid film, as would be expected from the presence of the hydroxyl groups. The films were very readily compressible, but this was due in part to an appreciable dissolution of the film, and owing to this effect it was impossible to determine the limiting area in the condensed state.

Magnesium Naphthalocyanine, Magnesium and Iron Phthalocyanines.—The solutions for spreading were made up in pyridine–benzene as above. The films given by these phthalocyanines were even less stable than those of hæmin, since these compounds contain no polar side chains at all. All formed very weak solid-condensed films, which even at the lowest compressions were never really homogeneous, surface-potential fluctuations of 10—20 mv. existing over different parts of the film. The *F–A* measurements gave areas at zero compression of about 50 A.[2], indicating that the molecules were vertically orientated as in the hæmin and protoporphyrin films, since if they were lying flat the area occupied would be at least 130 A.[2] (Crowfoot, *Ann. Reports*, 1936, **33**, 222). One property of these films was highly remarkable, and was shown particularly well by magnesium naphthalocyanine. A film of this compound of mean thickness certainly less than 30 A. could be seen with the unaided eye to possess the greenish-blue colour of the original compound in bulk. By means of a comparative test with an alcoholic solution, it was shown that the remarkably high molecular extinction coefficient possessed by this compound was of the same order in the film as in the bulk solution.



The dark-field examination confirmed the instability of the films. All three compounds gave an unusual fluorescent point structure, the fluorescence decreasing on compression and break lines then appearing.

Summary of Results.—For simplicity, the substituents in the molecular structures are denoted by reference to the inset skeleton.

Compound.	C_2.	C_3.	C_4.	C_6.	C_7.	Type of film.
Hæmin.	$CH:CH_2$	CH_3	$CH:CH_2$	$[CH_2]_2\cdot CO_2H$	$[CH_2]_2\cdot CO_2H$(+FeCl)	Solid.
Protoporphyrin.	,,	,,	,,	,,	,,	,,
Hæmatoporphyrin.	$CH(OH)\cdot CH_3$	,,	$CH(OH)\cdot CH_3$	,,	,,	Vapour expanded.
Mesoporphyrin dimethyl ester.	$CH_2\cdot CH_3$	,,	$CH_2\cdot CH_3$	$[CH_2]_2\cdot CO_2CH_3$	$[CH_2]_2\cdot CO_2CH_3$	Solid.
Chlorophyll-*a*.	$CH:CH_2$	,,	$CH_2\cdot CH_3$	$CO\cdot\overset{*}{C}H\cdot CO_2CH_3$	$[CH_2]_2\cdot CO_2C_{20}H_{39}$(+Mg)	Liquid expanded.
,, -*b*.	,,	*CHO*	,,	,,	,, ,,	,,

* Cyclised to C_γ.

Discussion of Results.

It appears that the presence or absence of a central metallic atom in the porphin ring system has a pronounced effect on the electric moment of the molecule, but has little effect on the intermolecular attractions or on the adhesion of the molecules to an aqueous sub-

strate, the latter being governed largely by the nature of the various side chains. Thus hæmin and protoporphyrin both give close-packed solid films differing only in electric moment. On the other hand, a striking difference is shown between these compounds and hæmatoporphyrin, in which the vinyl groups have been hydrated to $-CH(OH)\cdot CH_3$ groups. The adhesion to water has been increased sufficiently to overcome the intermolecular cohesion, so the film is vapour-expanded and forms no close-packed solid film. With mesoporphyrin dimethyl ester, where ethyl groups replace the vinyl, and the carboxyl groups have been esterified, we find once more the low adhesion to water and a high cohesion resulting in a solid film.

Examination of bilirubin shows the effect of free rotation in loss of cohesion and thus of molecular orientation.

Again, in the allied chlorophyll group it seems that removal of the metal by acids causes a change in electric moment without marked effect on the mechanical properties of the film. These properties are conditioned by the presence of the long phytol side chain, which ensures secure anchorage at an oil–water interface, at the same time permitting a large range of surface density of the molecules from $0{\cdot}75$—$1{\cdot}25 \times 10^{14}$ molecules/cm.^{2} (80—135 A.^{2}) in a liquid film, a consideration possibly of some significance in the action of chlorophyll at the surface of the chloroplasts.

The author's thanks are due to Profs. Stoll and Kuhn for the chlorophylls, Dr. Linstead for the phthalocyanines, Prof. Haurowitz for protoporphyrin, bilirubin, and mesoporphyrin dimethyl ester, and Prof. Keilin for hæmatoporphyrin. He also thanks Professor E. K. Rideal for his continued advice, and the Department of Scientific and Industrial Research for a maintenance grant.

DEPARTMENT OF COLLOID SCIENCE, CAMBRIDGE. [*Received, October 7th, 1937.*]

382. *The Thermochemistry of Perchloric Acid and the Perchlorates.*

By CHARLES F. GOODEVE and ARTHUR E. L. MARSH.

The heat of solution of dichlorine heptoxide has been measured, and this, combined with the value recently obtained for its heat of formation, gives a value for the heat of formation of aqueous perchloric acid. This provides a convenient basis for the thermochemistry of the perchlorates, since reliable data exist for the heats of neutralisation of perchloric acid, and the heats of solution of its salts. The new basis is about 7·5 kg.-cals. different from that previously used.

AT the commencement of this work the only available data for the heats of formation of perchloric acid and the perchlorates were those of Berthelot (*Ann. Chim. Phys.*, 1882, **27**, 214). In collaboration with Vieille (*ibid.*, p. 225) he determined the heat of reduction of potassium perchlorate as the difference between the heat of combustion of potassium picrate with pure oxygen on the one hand and with potassium perchlorate on the other. They found, for the equation

$$KClO_4 \longrightarrow KCl + 2O_2;\ \Delta U = +8{\cdot}6^* \quad . \quad . \quad . \quad (1)$$

The experiment was repeated with ammonium picrate in place of the potassium salt, and a value of + 6·5 obtained. The mean of the two values, + 7·5, together with Thomsen's value for the heat of formation of potassium chloride, 105, was used in calculating

$$K + \tfrac{1}{2}Cl_2 + 2O_2 \longrightarrow KClO_4;\ \Delta U_f = -112{\cdot}5 \quad . \quad . \quad . \quad (2)$$

This value is the basis of the heats of formation of the perchlorates given in Landolt–Börnstein.

Berthelot and Vieille do not give the value they obtained for the heat of combustion of the picrate. Calculation shows, however, that it is of the order of 400/g.-mol. of per-

* All heats of reaction are given in terms of kg.-cals.

chlorate ($2O_2$) and the limits of error in determining a small difference between two such large quantities must be very high.

Whereas Berthelot and Vieille found the reduction of potassium perchlorate [equation (1)] to be endothermic, Hofmann (*Sitzungsber. Akad. Wiss. Berlin*, 1932, 448), who repeated the experiments using paraffin in place of the picrate, found the reaction to be slightly exothermic, and obtained a value of $\Delta U = -1{\cdot}73 \pm 0{\cdot}07$ (or $\Delta H = -0{\cdot}55$). The values of the measured heats of combustion are again not given, but calculations show that they were of the order of 180/g.-mol. of perchlorate. In view of this, the accuracy claimed is unusually high.

Experimental.

Determination of the Heat of Solution.—Preliminary experiments revealed that the course of the reaction between dichlorine heptoxide and water consists of two stages; the first causes a rapid rise in temperature during about 2 min., and the second, a slow, steady rise for a further 5—15 mins. It was thought possible that the reaction proceeded *chemically* in two stages, with the initial formation of a fairly stable intermediate complex such as Cl_2O_7,H_2O. To test this point, the course of the reaction was followed in all experiments by measuring the conductivity simultaneously with the temperature.

Fig. 1a.

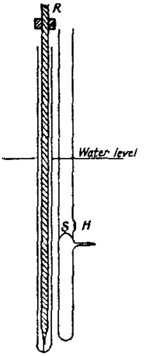


Fig. 1b.

Apparatus. A simple all-glass apparatus was designed (Fig. 1a) which enabled the dichlorine heptoxide to be manipulated without coming into contact with the atmosphere. The septum *S* and the lower, closed end were made as thin as possible. About 0·4 c.c. of the heptoxide was introduced through the side arm by vacuum distillation from a main reservoir. Slight traces of high-vapour-pressure impurities, such as chlorine dioxide, were then distilled off. The colour of the heptoxide at liquid-air temperature is very sensitive to such impurities; a slight trace of any other oxide turns it yellow or orange-red. The side arm was then sealed off at the constriction. A number of such samples were prepared at a time and stored in a solid carbon dioxide–alcohol mixture until required.

The conductivity cell is shown in Fig. 1b. Two thin platinum electrodes (3 mm. × 10 mm., and 5 mm. apart), coated with platinum-black, were sealed into Pyrex contact arms and protected by a coil of Pyrex rod. The cell was connected into the usual bridge circuit, a valve oscillator providing the source of alternating current. The heating effect of the conductivity cell was tested and found to be negligible.

A Dewar vessel of 250 c.c. capacity was used as a calorimeter. In order to protect it from draughts, it was set in a box loosely packed with asbestos wool and fitted with a lid. A very fast glass stirrer, driven by a constant-speed motor, was used to effect as rapid a dissolution of the heptoxide as possible. The temperature was observed with a Beckmann thermometer which could be read to 0·001°. In order to prevent the mercury thread sticking, the thermometer was automatically shaken by an electromagnetic hammer, as previously described (Goodeve and Marsh, this vol., p. 1161).

For each experiment the heat capacity was determined electrically in the usual way, standardised Weston instruments being used.

Procedure. At the commencement of an experiment one of the sample tubes was washed thoroughly free from alcohol and clamped in position in the calorimeter with the small hole *H* below the level of the water. Readings of temperature were taken at minute intervals, and when a steady state had been reached the glass rod *R* was quickly withdrawn and dropped down the centre of the sample tube. As soon as the septum *S* was shattered, water rushed in, and as the lower end was broken, the heptoxide fell as a large drop to the bottom of the calorimeter, just below the stirrer. Readings of temperature and conductivity were taken every minute until a steady state was again reached. The rise in temperature due to the reaction was found by plotting temperature against time and extrapolating the initial and the final steady state. This extrapolation could be made accurately, as the rate of rise of temperature in the two states was almost identical. Irregular external heat effects occurring while the heptoxide was dissolving

were shown to be absent by a comparison between the temperature rise and the conductivity. The solution of perchloric acid formed was subsequently diluted to 500 c.c., and about six 25-c.c. samples titrated against N/100-sodium hydroxide.

Results and Discussion.

The values obtained for the heat of reaction of dichlorine heptoxide with excess water (final concentrations about N/100-perchloric acid) are given in Table I, together with other experimental details.

In experiments A, 1, 3, and 5, the stirring was irregular and the results are consequently less accurate. In B, 1 a different apparatus was employed for the conductivity measurements and the heating effect was found to be appreciable. The circuit was subsequently altered to eliminate this heating effect. Expts. B, 2, 3, and 4 were carried out with impure

Table I.

Expt. No.	Heat capacity, cals./° C.	Cl_2O_7 used, g.-mols. × 10^3.	ΔT.	ΔH, kg.-cals.	Statistical weight.
A, 1	275·0	1·241	0·228°	−50·2	2 †
A, 2	274·0	1·419	0·259	−50·0	4
A, 3	273·3	1·006	0·180	−48·8	1 † §
A, 4	264·5	1·875	0·361	−50·8	4
A, 5	268·8	1·528	0·291	−49·5	1 † §
A, 6	279·7	2·360	0·410	−48·5	4
B, 1	276·8	1·520	0·284	−51·3	2 § *
B, 2	267·3	1·067	0·189	−48·2	0 ‡
B, 3	258·3	0·950	0·180	−48·9	0 ‡
B, 4	273·5	1·731	0·313	−49·4	0 ‡
B, 5	264·9	0·727	0·137	−49·7	3 §
B, 6	264·9	1·230	0·232	−50·1	4
B, 7	255·5	1·324	0·262	−50·4	4
			Weighted mean =	−50·0 kg.-cals.	

† Stirring irregular. ‡ Impure sample. § Steady state uncertain.
* Heating effect due to conductivity cell.

samples, and the results obtained were consequently neglected in calculating the mean value for the heat of the reaction. An approximate statistical weight, based upon the above considerations, has been given to each value in calculating the mean: $\Delta H = -50{\cdot}0$/g.-mol. of dichlorine heptoxide, with a probable error of $\pm 0{\cdot}5$.

The formation of a fairly stable intermediate hydrate such as Cl_2O_7,H_2O has been suggested above as a possible explanation of the slow rate of solution of dichlorine heptoxide in water. Such a complex would not be ionised, and no change in the conductivity of the solution would be observed until it dissociated into perchloric acid. No such delay was observed, however, and the conductivity was found to follow the rise of temperature exactly (the conductivity is proportional to the amount of perchloric acid at the low concentrations used here).

The value of ΔH measured in the experiments is, therefore, the heat of the following reaction:

$$\left.\begin{array}{l} Cl_2O_7 + H_2O + aq. \longrightarrow 2HClO_4\ (aq.)\ (N/100) \\ \quad\text{or} \qquad\qquad\quad \longrightarrow 2H^+\ (aq.) + 2ClO_4^-\ (aq.) \end{array}\right\} \Delta U \text{ and } \Delta H = -50{\cdot}0 \pm 0{\cdot}5 \quad . \quad (3)$$

The slow rate of rise of temperature was almost certainly due to a slow rate of solution of the drop of dichlorine heptoxide. This was observed in preliminary trials in glass vessels, and confirmed the previous observations of Michael and Conn (*Amer. Chem. J.*, 1900, **23**, 444), who found that this oxide, when poured into water, sank to the bottom and dissolved slowly. The slowness of the reaction is surprising in view of the great affinity of the heptoxide for water, as shown by the instantaneous fuming of the gaseous oxide in air. The interfacial tension between liquid heptoxide and water was high and remained so throughout the dissolution of the drop. Perchloric acid is miscible with water in all proportions and if it were likewise miscible with the heptoxide it would be impossible for a boundary to be set up which could exhibit a surface tension. One concludes, therefore, that there is a limited solubility of perchloric acid in the heptoxide. The initial rapid rise of temperature can be attributed to the setting up of saturation at least in the outer parts of the drop, and

the subsequent slow rise to the gradual diffusion of water through a thin perchloric acid layer *outside* the drop. This is supported by the fact that the rate of reaction during the period of slow rise in temperature was directly proportional to the calculated surface area of the drop.

Thermochemical Data.—By means of the following heats of reaction :

$$Cl_2 + 3\tfrac{1}{2}O_2 \longrightarrow Cl_2O_7 \text{ (gas)};\ \Delta H_f = +63{\cdot}4 \pm 3 \quad . \quad . \quad . \quad . \quad (4)$$

(Goodeve and Marsh, this vol., p. 1161)

$$Cl_2O_7 \text{ (gas)} \longrightarrow Cl_2O_7 \text{ (liq.)};\ \Delta H = -8{\cdot}3 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

(Goodeve and Powney, J., 1932, 2078)

$$Cl_2O_7 \text{ (liq.)} + H_2O \text{ (liq.)} + \text{aq.} \longrightarrow 2HClO_4 \text{ (aq.)};\ \Delta H = -50{\cdot}0 \pm 0{\cdot}5 \quad . \quad . \quad . \quad (3)$$

$$H_2 + \tfrac{1}{2}O_2 \longrightarrow H_2O \text{ (liq.)};\ \Delta H_f = -68{\cdot}4 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

one obtains the heat of formation of aqueous perchloric acid,

$$\tfrac{1}{2}H_2 + \tfrac{1}{2}Cl_2 + 2O_2 + \text{aq.} \longrightarrow HClO_4 \text{ (aq.)};\ \Delta H_f = -31{\cdot}6_5 \pm 1{\cdot}7 \quad . \quad . \quad . \quad (7)$$

The value calculated by Berthelot was — 39·1.

In Table II the heats of formation of the crystalline perchlorates, calculated on the basis of equation (7), are given, together with the other thermochemical data employed. The concentrations of perchloric acid used by Berthelot in determining its heats of neutralisation (given in col. 3) are greater than those attained in the present work on the heat of solution of the heptoxide. Consideration of Berthelot's data for the heat of dilution of aqueous perchloric acid, however, shows that the correction is negligible.

TABLE II.

$MClO_4$.	$\Delta H_f MOH$(aq.), kg.-cals.	ΔH neutralisation, kg.-cals.	$\Delta H_f MClO_4$(aq.), kg.-cals.	$\Delta H_s MClO_4$, kg.-cals.	$\Delta H_f MClO_4$, kg.-cals.
$NaClO_4$	−112·05 (0·166N)	−14·25	− 89·5 (0·08N)	+ 3·5 (0·215* and 0·005N †)	− 93·0
$KClO_4$	−114·83 (0·083N)	−14·25	− 92·3 (0·04N)	+12·1 (0·32 ‡ and 0·03N §)	−104·4
NH_4ClO_4	− 87·72 (0·25N)	−12·90	− 63·8 (0·10N)	+ 6·36 (0·2N ‡)	− 70·2
$Ba(ClO_4)_2$	−237·50 (0·166N)	−28·94	−192·8 (0·08N)	+ 1·42 (0·126N *)	−194·3

* Smeets (*Natuurwetensch. Tijds.*, 1933, **15**, 105). † Askew *et al.* (J., 1934, 1368).
‡ Berthelot (*loc. cit.*). § Latimer and Ahlberg (*J. Amer. Chem. Soc.*, 1930, **52**, 539).

The values used for the heats of formation of the aqueous hydroxides (col. 2) are those given by Bichowsky and Rossini ("Thermochemistry of Chemical Substances," 1936). Values for the heats of solution (ΔH_s) of the perchlorates, and the corresponding normality of the solutions, are given in col. 5.

The new value for equation (2) leads to a value of $\Delta H = +0{\cdot}2 \pm 1{\cdot}7$ for equation (1), on the basis of ΔH_fKCl = — 104·2 (Landolt–Börnstein). Despite its high limits of error, arising out of possible errors in equation (4), the new value is in good agreement with the result of Hofmann, who found for equation (1) $\Delta H = -0{\cdot}55$. This agreement justifies a reduction in the limits of error of equation (4) from ± 3 to ± 1·5, giving to equation (7) and to the heats of formation of the perchlorates a limit of error of less than ± 1.

Berthelot determined the heat of dilution of pure perchloric acid and obtained a value of $\Delta H = -20$. This is not very reliable, however, for, as he remarks, " the experiments were difficult owing to the rapidity with which the acid attracted moisture during weighing, and the violence of the reaction with water when the experiment was carried out." The heat of formation of pure perchloric acid has not, therefore, been calculated here.

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383. *The Minor Alkaloids of* Duboisia myoporoides.

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In addition to hyoscine, the Australian drug yielded three new alkaloids. Tigloidine, $C_{13}H_{21}O_2N$, a syrup, is tiglyl-ψ-tropëine and has been synthesised. Valeroidine, $C_{13}H_{23}O_3N$, m. p. 85°, $[\alpha]_D^{20°}$ −9·0°, is the *iso*valeryl ester of a dihydroxytropane, obtained by Wolfes and Hromatka (*Merck's Jahresber.*, 1933, **47**, 45) as a by-product in the manufacture of cocaine from Peruvian coca leaves. The third alkaloid, $C_{12}H_{21}O_2N$, provisionally called base Z, is syrupy and yields a crystalline *oxalate*. The yields were respectively 0·1, 0·1, and 0·003% of the drug. The first base and the third are characterised by hydrobromides which are extracted as such from aqueous solution by chloroform. Dihydrotigloidine, dibromodihydrotigloidine, and tiglyltropëine have also been prepared. The hydrobromides of acetyltropëine and acetyl-ψ-tropëine are useful for characterising tropine and ψ-tropine respectively.

The (somewhat old) literature on *Duboisia myoporoides* is very confusing. E. Merck (*Arch. Pharm.*, 1893, **231**, 117) found hyoscine, hyoscyamine and a supposed isomeride of the latter, termed ψ-hyoscyamine. Carr and Reynolds (J., 1912, **101**, 946) isolated from *D. myoporoides* of Philippine origin 1·1% of hyoscyamine and 0·15% of a new alkaloid, norhyoscyamine; they questioned the purity of Merck's ψ-hyoscyamine and regarded it as norhyoscyamine contaminated with hyoscyamine; they did not refer to the isolation of hyoscine, presumably not found. In present-day pharmaceutical literature "duboisine," of which salts appear in commerce, is stated to be a mixture of hyoscine and hyoscyamine. Ladenburg (*Ber.*, 1880, **13**, 257) found such a commercial sample to consist largely of hyoscyamine, a later one mainly of hyoscine. The latter result (Ladenburg and Petersen, *Ber.*, 1887, **20**, 1661) appears to-day rather doubtful; the free base was not isolated, but an aurichloride corresponding fairly closely to $C_{17}H_{23}O_3N,HCl,AuCl_3$ and to Ladenburg's hyoscine formula; the true formula for hyoscine was however shown by Hesse to be $C_{17}H_{21}O_4N$, so Ladenburg's identification is very doubtful. A recent sample of "duboisine sulphate" examined by us proved to consist almost entirely of hyoscyamine sulphate and no trace of hyoscine was detectable. Since hyoscine and hyoscyamine are now well defined, the term "duboisine," applied to mixtures supposedly obtained from the Australian drug, should be abandoned. Other varieties or species may contain different alkaloids (compare *D. myoporoides* from the Philippines mentioned above). The Australian *D. Hopwoodii* contains nornicotine (Späth, Hicks, and Zajic, *Ber.*, 1935, **68**, 1388).

One of us (W. F. M.) has during recent years examined consignments of *D. myoporoides*, collected in various Australian districts at different seasons, and found considerable variation, both in the total alkaloidal content and in the proportion of the individual alkaloids; in no case could hyoscyamine be isolated. Generally the consignments consisted of carefully dried material, mostly leaves, with some small twigs and occasionally small berries. The odour was quite characteristic, not unpleasant and somewhat butyric. After the more or less complete separation of hyoscine, three new alkaloids were isolated by him; for two of these the names tigloidine and valeroidine are now suggested, since they are esters of tiglic and *iso*valeric acid respectively; the third alkaloid is provisionally referred to as base Z. None of these alkaloids gives the Vitali reaction (for tropic acid), a fact which at once distinguishes them from hyoscine or any of the alkaloids found by other workers. With the exception of a little *dl*-hyoscine, no other alkaloid could be isolated.

Tigloidine, $C_{13}H_{21}O_2N$, a thin colourless syrup, has a narcotic odour when warm and is a strong tertiary base. It is optically inactive and contains one double bond, readily reduced catalytically; it adds bromine slowly. Among various characteristic salts the *hydrobromide* is peculiar in being soluble in chloroform (1 in 3). On hydrolysis tigloidine yields tiglic acid, $C_5H_8O_2$, and ψ-tropine, $C_8H_{15}ON$, so it is tiglyl-ψ-tropëine, a fact which we have confirmed by its synthesis from tiglyl chloride and ψ-tropine hydrochloride (according to a general method employed by Jowett and Pyman, J., 1909, **95**, 1024).

Tiglic acid appears to have been obtained so far only by hydrolysis of two other alkaloids: cevadine from *Veratrum sabadilla* (Wright and Luff, J., 1878, **33**, 347) and meteloidine from *Datura meteloides* (Pyman and Reynolds, J., 1908, **93**, 2077); ψ-tropine has hitherto been obtained from one alkaloid only, tropacocaine from Javanese coca leaves (Giesel and Liebermann, *Ber.*, 1891, **24**, 2336). Since both tiglic acid and ψ-tropine have geometric isomerides, three stereoisomerides of tigloidine are conceivable; we have synthesised one of these, tiglyltropeïne.

Valeroidine, $C_{13}H_{23}O_3N$, colourless nacreous plates, melts at 85° (corr.) and like tigloidine is a strong tertiary base. It has one free hydroxyl group, and is saturated. Its *hydrobromide* is only sparingly soluble in chloroform, and this difference from tigloidine is utilised in the separation of the two alkaloids (see experimental part). They can also be distinguished by Mayer's reagent, to which tigloidine behaves normally; valeroidine, on the other hand, gives a precipitate in concentrated solution only, and the precipitate is, moreover, readily soluble in dilute acids. Valeroidine is lævorotatory; its hydrobromide is dextrorotatory. On hydrolysis equimolecular proportions of *iso*valeric acid, $C_5H_{10}O_2$, and a crystalline, lævorotatory base, $C_8H_{15}O_2N$, m. p. 212° (corr.), are formed; the base was found to be identical with the dihydroxytropane separated as dibenzoyl ester from Peruvian coca leaves by Wolfes and Hromatka (*Merck's Jahresber.*, 1933, **47**, 45). We are indebted to Messrs. Merck of Darmstadt for a generous supply of this base and of the sulphate of its dibenzoyl ester, for which we tender our best thanks. Since this dihydroxytropane was obtained from the residues of the industrial partial synthesis of cocaine from ecgonine, it probably does not occur in coca leaves as such, but was formed by hydrolysis of the crude alkaloids in the manufacture of ecgonine. It is of interest to note that the chemistry of the alkaloids of *D. myoporoides* (N. O. *Solanaceæ*) resembles that of the alkaloids of *Erythroxylon Coca* (*N. O. Erythroxylaceæ*) in at least two points: both plants, widely separated taxonomically, yield ψ-tropine and dihydroxytropane, two bases not known to be produced by any other plant. Valeroidine is thus mono*iso*valeryldihydroxytropane and the first alkaloid to have yielded a pentoic acid by hydrolysis; this is represented in tigloidine by an unsaturated and in base Z apparently by a saturated acid with five carbon atoms. Gerrard (*Pharm. J.*, 1877, **8**, 787), probably the earliest worker on Australian *D. myoporoides*, already observed on hydrolysis of the total alkaloid an odour "resembling butyric acid" (not noticed by later workers). In spite of his injunction not to apply the term "duboisine" to an impure substance, this term crept into the literature.

Base Z, $C_{12}H_{21}O_2N$, a thin, colourless, strongly basic syrup, has a narcotic odour when warm. It resembles valeroidine in its behaviour to Mayer's reagent and tigloidine in forming a hydrobromide soluble in chloroform (1 in 0·4; much more even than tigloidine hydrobromide). Base Z forms a characteristic *oxalate*, used in its isolation, and is being investigated further.

EXPERIMENTAL.

Separation and Isolation of the Three Alkaloids.—The drug (No. 20 powder) was extracted with alcohol, and from the total alkaloids hyoscine was separated by the usual methods. The concentrated aqueous solution of the residual hydrobromides was extracted with chloroform, which removed most of the hydrobromides of tigloidine and base Z. On evaporation of the chloroform the tigloidine salt crystallised and the residual syrupy hydrobromide of base Z was converted into a neutral oxalate which slowly crystallised on concentration of its aqueous solution. The hydrobromides left in aqueous solution (from which the chloroform-soluble portion had been removed) were also converted into neutral oxalates; from their concentrated solution in water, valeroidine oxalate slowly crystallised (at first thought to be hyoscyamine oxalate). After reconversion into hydrobromides a small amount of *dl*-hyoscine was separated from the residual alkaloids, but no other base. The crude tigloidine hydrobromide was recrystallised from water. The *valeroidine oxalate* was converted into hydrobromide, which was recrystallised by adding ether to its warm alcoholic solution. The oxalate of base Z was recrystallised from water. A good average sample of the drug yielded: tigloidine 0·1, valeroidine 0·1, base Z 0·003%.

Tigloidine is sparingly soluble in cold water, readily in most organic solvents. The *hydrobromide*, colourless, anhydrous, tabular crystals (from water), m. p. 234—235° (corr.), is

moderately soluble in water and in alcohol, readily in chloroform (*ca.* 1 : 3), almost insoluble in ether (Found: C, 51·4; H, 7·4; N, 4·6; Br, 26·1. $C_{13}H_{21}O_2N$,HBr requires C, 51·3; H, 7·3; N, 4·6; Br, 26·3%), and is optically inactive (*c*, 5·0 in water). The methiodide was prepared from the base (0·2 g.) in dry ether (10 c.c.) and methyl iodide (0·5 c.c.), and separated overnight at room temperature; recrystallised from alcohol–ether, it formed square plates, m. p. 244—245° (corr.), readily soluble in water and in alcohol. The picrate, from the base (0·2 g.) in N/50-hydrochloric acid (5 c.c.) and saturated aqueous picric acid solution in slight excess, formed rectangular plates (from 45% alcohol), m. p. 239° (corr.), soluble in alcohol and in acetone, but very sparingly in water. The aurichloride, prepared like the picrate, formed golden-yellow plates (from aqueous acetone), m. p. 213·5—214° (corr.), readily soluble in acetone, hardly in water.

Dihydrotigloidine.—Tigloidine hydrobromide (1 g.) in water (25 c.c.) was shaken with platinum oxide (0·1 g.) in hydrogen. Absorption ceased after 50 minutes when 1 mol. had been taken up. After filtration, basification with ammonia, and extraction with chloroform, the theoretical amount (0·74 g.) of a thin syrup was obtained. The *hydrobromide* formed stout prisms (from alcohol–ether), m. p. 186—187° (corr.) (Found: C, 51·2; H, 7·9. $C_{13}H_{23}O_2N$,HBr requires C, 51·0; H, 7·8%), the methiodide was a microcrystalline powder, m. p. 209° (corr.), the picrate crystallised in plates, m. p. 134·5° (corr.), and the aurichloride in orange-yellow plates, m. p. 151° (corr.). The last two salts are rather more soluble in water than the corresponding tigloidine salts.

Dibromodihydrotigloidine.—Bromine (0·1 c.c.) was added to tigloidine hydrobromide (0·6 g.) in chloroform (10 c.c.). The solution became almost colourless in 3 days; after evaporation the faintly yellow, crystalline residue was recrystallised from a little 25% alcohol, giving stout colourless prisms, m. p. 196° (corr.; decomp.), soluble in alcohol, sparingly in water. Yield, 80%. The free base, obtained from this hydrobromide, became solid on evaporation of the chloroform. After being washed with acetone, it separated from alcohol–ether as a white microcrystalline powder, m. p. 187° (corr.; decomp.).

Hydrolysis of Tigloidine.—The base from 1 g. of hydrobromide was boiled for 1 hour with barium hydroxide (1·5 g.) in water (25 c.c.). On extraction of the solution with ether and evaporation of this solvent, the minute residue obtained neutralised 0·25 c.c. of N/10-sulphuric acid (equivalent to 0·006 g. of tigloidine). After removal of the barium as sulphate from the aqueous layer, so extracted, the acid filtrate was shaken with ether, which left 0·318 g. of an acid forming stout prisms from hot water, m. p. 64·5° (corr.), not depressed by tiglic acid (Found: equiv., 100. Calc. for $C_5H_8O_2$: equiv., 100). Yield, 97%. The dibromide, prepared in chloroform solution, formed long needles from light petroleum, m. p. 88° (corr.), not depressed by an authentic specimen.

The solution from which the tiglic acid had been extracted was freed from sulphuric acid by barium carbonate; the filtrate and washings were exactly neutralised with sulphuric acid, filtered, and evaporated. The almost colourless, distinctly hygroscopic residue (0·606 g.) gave reactions for chloride (as well as sulphate; compare the similar behaviour of teloidine, from meteloidine; Pyman and Reynolds, *loc. cit.*). Chloride and sulphate ions were removed by a slight excess of potassium hydroxide in alcohol; the filtrate then left 0·353 g. of a crystalline residue. After sublimation at 1 mm., needles were obtained from benzene–ligroin, m. p. 108° (corr.), not depressed by ψ-tropine. Yield, 76%. A portion was converted into acetyl-ψ-tropëine hydrobromide, which melted at 205° (corr.), alone and mixed with an authentic specimen.

Hydrobromides of Acetyltropëine and Acetyl-ψ-tropëine.—These compounds, which do not appear to have been described, have been found useful in identifying tropine and ψ-tropine; they are prepared by refluxing the bases with acetic anhydride for a few hours; after addition of water, basification with ammonia, and extraction with chloroform, the residue is neutralised with hydrobromic acid and crystallised from alcohol–ether. *Acetyltropëine hydrobromide* forms stout prismatic needles, m. p. 187—187·5° (corr.) (Found: N, 5·3. $C_{10}H_{17}O_2N$,HBr requires N, 5·3%). The corresponding methiodide forms glistening needles, m. p. 279—280° (corr.). The picrate, m. p. 217° (corr.), is moderately soluble in water. Acetyl-ψ-tropëine hydrobromide forms stout prisms, m. p. 205° (corr.).

Synthesis of Tigloidine.—Tiglic acid (4 g.) and phosphorus trichloride (3 g.) were heated together at 70—80° for 2 hours; the upper, slightly yellow layer was decanted from the syrupy lower layer and distilled at 64°/35 mm.; yield, 90%. Tiglyl chloride so obtained (0·25 g.) was refluxed with ψ-tropine hydrochloride (0·3 g.) for 4 hours on the water-bath. The pale yellow, syrupy product was dissolved in very dilute hydrochloric acid and washed

with ether to remove tiglic acid, then basified and extracted with chloroform. The residue on neutralisation with hydrobromic acid and evaporation yielded 0·47 g. (87%) of a crystalline hydrobromide. After solution in chloroform, filtration, and crystallisation from alcohol–ether, prisms separated, m. p. 234·5° (corr.), identical with the natural product (Found : C, 50·9; H, 7·2; N, 4·6; Br, 26·3. Calc. for $C_{13}H_{21}O_2N,HBr$: C, 51·3; H, 7·3; N, 4·6; Br, 26·3%). The methiodide had m. p. 244° (corr.), not depressed by tigloidine methiodide.

Synthesis of Tiglyltropeine Hydrobromide.—Prepared as above, from tropine hydrochloride (0·5 g.) and tiglyl chloride (0·33 g.) in 46% yield, this formed rectangular laminæ, m. p. 207° (corr.) (Found : N, 4·4. $C_{13}H_{21}O_2N,HBr$ requires N, 4·6%). The substance was evidently not quite pure, but repeated recrystallisation failed to raise its m. p. The picrate formed golden-yellow plates with feathery edges, m. p. 200° (corr.), sparingly soluble in water, and the methiodide, colourless laminæ, m. p. 289—290° (corr.).

Valeroidine.—This formed soft laminar crystals, m. p. 85°, readily soluble in ether, alcohol, chloroform and water, sparingly in light petroleum. $[\alpha]_D^{20°}$ −9·0 (*c*, 5·0 in absolute alcohol) and − 4·0° (*c*, 5·0 in water). The *hydrobromide* crystallised in small needles from alcohol–ether, m. p. 170—172° (corr.) (lower figures were obtained unless the temperature was raised very slowly). $[\alpha]_D^{20°}$ + 5·0° (*c*, 20 in water) and + 2·5° (*c*, 20 in absolute alcohol) (Found : C, 48·2; H, 7·7; N, 4·3; Br, 24·4. $C_{13}H_{23}O_3N,HBr$ requires C, 48·4; H, 7·5; N, 4·3; Br, 24·8%). The oxalate, prepared by neutralisation of the base with oxalic acid, formed long prismatic needles, m. p. 202° (corr.), sparingly soluble in water. The methiodide, prepared in dry ether at room temperature and recrystallised from methanol–ether, formed six-sided laminæ, m. p. 205·5° (corr.), soluble in methyl alcohol, sparingly in ethyl alcohol. The picrate separated in needles from water, m. p. 152—153° (corr.), moderately soluble in water. The aurichloride was a yellow oil.

Hydrolysis of Valeroidine.—The method was the same as that for tigloidine. The oily acid obtained (0·245 g. from 1 g. of valeroidine hydrobromide) had a powerful odour of valeric acid and was optically inactive (*c*, 2·45 in 60% alcohol) (Found : equiv., 101. Calc. for $C_5H_{10}O_2$: equiv., 102). Yield, 77%. It was characterised as the *p*-phenylphenacyl ester and the anilide. The acid (0·24 g.) was almost neutralised with sodium carbonate, and the solution concentrated (3 c.c.) and refluxed with *p*-phenylphenacyl bromide (0·5 g.) in 95% alcohol (10 c.c.). *p*-Phenylphenacyl *iso*valerate crystallised over-night and was recrystallised from 50% alcohol, forming colourless foliated masses, m. p. 76° (corr.), not depressed by a specimen prepared from authentic *iso*valeric acid. The anilide was obtained by refluxing the acid (1·5 g.) with aniline (1 g.) and repeatedly crystallised from 70% alcohol (charcoal); m. p. 114° (corr.), not depressed by an authentic specimen having the same m. p. (the literature gives m. p. 115°).

The basic fission product of valeroidine formed large, colourless, tabular crystals from alcohol–ether, m. p. 212° (corr.) (not raised by sublimation at 1 mm.). In its separation as sulphate, no trace of chloride was found. Yield, 100% (0·487 g. from 1 g. of valeroidine hydrobromide) [Found : C, 61·0; H, 9·7; N, 9·2; (N)CH_3, 7·9; active H, 1·43; equiv., 156. Calc. for dihydroxytropane, $C_8H_{15}O_2N$: C, 61·1; H, 9·6; N, 8·9; (N)CH_3, 9·5; active H, 2·0%; equiv., 157]. $[\alpha]_D^{20°}$ − 25·0° (*c*, 2·0 in absolute alcohol) and − 16·0° (*c*, 4·0 in water). The substance was in all respects similar to the dihydroxytropane from Peruvian coca leaves, supplied by Messrs. E. Merck. Both bases and their mixture melted at 212° (corr.); the Merck base had $[\alpha]_D^{21°}$ − 22·0° (*c*, 2·0 in absolute alcohol). This dihydroxytropane is a strong base, freely soluble in water and in alcohol, sparingly in ether. It is being investigated further.

Base Z.—This is a syrup, sparingly soluble in water and in ether, freely in alcohol and in chloroform. The *oxalate*, soft nacreous laminæ, m. p. 285—290° (corr.), crystallises from water, in which it is sparingly soluble in the cold [Found : C, 60·9; H, 8·6; N, 5·5; $H_2C_2O_4$, 17·6. $(C_{12}H_{21}O_2N)_2,H_2C_2O_4$ requires C, 60·9; H, 8·6; N, 5·5; $H_2C_2O_4$, 17·6%]. It is optically inactive (*c*, 1·0 in water). The hydrobromide forms similar crystals from alcohol–ether, m. p. 219—220° (corr.). It is very soluble in chloroform (*ca.* 1 in 0·4); the saturated solution is viscous.

The isolation and purification of these alkaloids were carried out by one of us (W. F. M.) in the laboratories of Messrs. T. & H. Smith, Ltd., Edinburgh, to which firm our best thanks are recorded for generous supplies both of the drug and of the separated alkaloids. The work on their constitution is by the other two authors, one of whom (W. M.) desires to express his gratitude to Messrs. T. & H. Smith, Ltd., for facilities to carry it out.

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384. *Mercurous Perchlorate as a Volumetric Reagent for Chlorides and Bromides.*

By W. Pugh.

Mercurous perchlorate, in conjunction with bromophenol-blue as adsorption indicator, has been used as a volumetric reagent for chlorides and bromides, and found to give excellent results.

With bromophenol-blue as adsorption indicator, mercurous nitrate is well established as a volumetric reagent for chlorides and bromides (von Zombory, *Z. anorg. Chem.*, 1929, **184**, 237); it has the advantage over silver nitrate that it can be applied in acid solution. Mercurous perchlorate is now shown to give equally good results and to have certain advantages. Its solutions are reasonably stable when kept under appropriate conditions; they are easy to prepare, are free from interfering mercuric ions, and give sharp end-points which coincide exactly with the equivalent points.

Preparation and Standardisation of Mercurous Perchlorate Solution.—The preparation and properties of mercurous perchlorate have been described by Newbery (*Trans. Electrochem. Soc.*, 1936, **69**, 611), who suggested that it might replace silver nitrate as a bench reagent in qualitative analysis. The solutions used in this investigation were made by shaking the following materials vigorously together at intervals over a period of an hour: red mercuric oxide (22 g.), perchloric acid (*d* 1·5; 45 g.), water (50 c.c.), and mercury (30 g.). A few drops of the liquid were withdrawn from time to time, diluted, treated with sodium chloride, and filtered. When the filtrate from this test portion ceased to give the test for mercuric ions with hydrogen sulphide, the liquid was decanted or filtered from the excess of mercury and diluted to 2 l. Such a solution is approximately 0·1N.

The solution was standardised immediately by electrolytic determination of mercury, by potentiometric titration of sodium chloride by using the mercury electrode (Muller and Aarflot, *Rec. trav. chim.*, 1924, **43**, 874), by titration of pure sodium chloride and potassium bromide with bromophenol-blue, and by Andrews's method with potassium iodate. All these methods gave identical results. For the titration of sodium chloride and potassium bromide, the solution of the halide was diluted to about 100 c.c., ½ c.c. of bromophenol-blue (0·05% in water) added, and the mercurous perchlorate solution run in until the colour of the precipitate changed from creamy white to lilac. This colour change is produced by a small fraction of a drop, especially if the addition of the indicator is delayed till near the end-point.

Influence of acids and salts. Nitric, perchloric, and acetic acids have no effect on the accuracy of the titration if the total acid concentration does not exceed 0·04N.; higher concentrations inhibit the colour change. Sulphuric acid causes a high titre. Silver ions and mercuric ions are the only cations which affect the method, the latter reducing the titre by an amount proportional to their concentration. This is due to the removal of some of the halide ions as undissociated mercuric halide. Hence, mercurous perchlorate which is free from mercuric ions has a distinct advantage over mercurous nitrate. Apart from the anions of weak acids, which yield insoluble mercurous salts, sulphate ion is the only anion that interferes, as little as 10 mg. of sodium sulphate raising the titre by 1%. This effect is completely eliminated, however, by adding an excess of lead nitrate to the boiling solution. The lead sulphate need not be filtered off before titration, but precipitation in the cold gives low results.

Stability of Mercurous Perchlorate Solutions.—Solutions examined over a period of 4 months behaved differently according as they had been exposed to light or kept in the dark. The former underwent considerable decomposition into mercury and mercuric perchlorate; the iodate titre diminished steadily. The curious point, however, is that, in its behaviour towards sodium chloride, the solution showed an apparent increase of strength, which rose fairly rapidly during the first few days and then more slowly till after 4 months it had increased by 2·5%. The iodate titre had decreased during the same period by less than 1%. Evidently, mercuric ions affect the titre not only by binding halide ions but also by inducing premature adsorption of the indicator.

On the other hand, solutions kept in the dark were reasonably stable. The iodate titre decreased by 0·4% but the sodium chloride titre remained almost unchanged during the whole

period, being only 0·1% low after 4 months. Keeping the solutions over mercury or increasing the concentration of free perchloric acid had no effect whatever.

Details of Method.—Dilute the solution of the halide to about 100 c.c. If sulphates are present, boil it, add 10—20 c.c. of lead nitrate solution (5%), and cool. Add a drop of bromophenol-blue, then ammonia or sodium carbonate till the indicator turns faintly blue, and titrate with 0·1 or 0·05N-mercurous perchlorate. Just before the end-point is reached, add 0·5 c.c. of bromophenol-blue and continue the titration till the colour of the precipitate changes to lilac.

Some Typical Analyses.—The above method was used to determine chlorine in some pure products and in some natural waters. With pure lead chloride and barium chloride the results obtained were excellent: $PbCl_2$ (Found: Cl, 25·48, 25·48. Calc.: 25·50%); $BaCl_2,2H_2O$ (Found: Cl, 29·01, 29·03. Calc.: 29·03%). The results for various natural waters are in the table, which also includes the results of check determinations made by other methods. The boiler water was almost black, but the addition of lead nitrate to remove the sulphate gave a colourless filtrate and there was no difficulty in getting a sharp end-point.

	Chlorine found.		
Method.	Gravimetric.	Mohr.	$HgClO_4$.
Sea water, %	1·935, 1·934	1·940, 1·941	1·937, 1·937
Well water, parts per 100,000	13·61, 13·58	13·9	13·4, 13·6
Boiler water, parts per 100,000	58·3, 58·3	60·2, 60·5	58·3, 58·4
Drinking water, parts per 100,000	—	2·2	2·1

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385. *Glucosides related to Carcinogenic Hydrocarbons.*

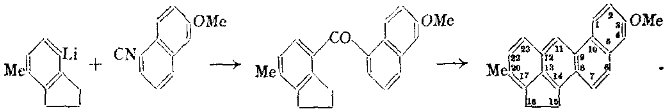
By J. W. COOK and C. G. M. DE WORMS.

Attempts have been made to synthesise water-soluble cancer-producing compounds which might be expected to have interesting biological properties. Methylcholanthrene is a potent cancer-producing hydrocarbon which can be prepared from the bile acids, and a methylhydroxycholanthrene has been synthesised in which the hydroxyl group occupies the position in the molecule characteristic of the hydroxyl group of many natural sterols. This methylhydroxycholanthrene was converted into its tetra-acetylglucoside, which was hydrolysed to an amorphous glucoside, insoluble in water. In the meantime, it has been found that the methylhydroxycholanthrene has no cancer-producing activity and hence provides an unsuitable basis for the purpose in view. Parallel experiments, with similar results, have been carried out with a hydroxy-derivative of 3 : 4-benzpyrene, a potent cancer-producing hydrocarbon present in coal tar.

APART from the molecular complexes of carcinogenic hydrocarbons with sodium deoxycholate (Fieser and Newman, *J. Amer. Chem. Soc.*, 1935, **57**, 1602) the only water-soluble carcinogenic compound at present available is sodium 1 : 2 : 5 : 6-dibenzanthracene-9 : 10-*endo*-αβ-succinate (Cook, J., 1931, 3273; Burrows and Cook, *Amer. J. Cancer*, 1936, **27**, 267), the potency of which is rather low, and it seemed possible that suitable water-soluble derivatives of the very active carcinogenic hydrocarbons cholanthrene and 3 : 4-benzpyrene might be more potent. Moreover, the conversion of a carcinogenic hydroxy-compound into a water-soluble derivative (*e.g.*, by combination with a sugar) which would undergo hydrolysis in the animal body might enable one to produce cancer at other sites than that of application of the carcinogenic substance. In the choice of a suitable hydroxy-derivative of cholanthrene for such experiments we were guided by the consideration that, if the transformation of a bile acid into a methylcholanthrene type of molecule happens to occur in the body, the ultimate product might well retain the hydroxyl group at position 3 (sterol system of numbering) characteristic of so many of the natural products of the sterol group.

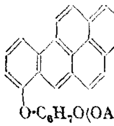
We had a choice of four synthetic methods for the preparation of the cholanthrene ring system, and that due to Fieser and Seligman (*J. Amer. Chem. Soc.*, 1935, **57**, 942)

seemed the most suitable for the desired methylhydroxycholanthrene. The magnesio-derivative of 7-bromo-4-methylhydrindene is very slowly formed, and we found it more convenient to employ 4-methylhydrindyl-7-lithium (I) for interaction with 6-methoxy-1-naphthonitrile (II), a compound which we had already synthesised when it was described by Butenandt and Schramm (*Ber.*, 1935, **68**, 2083). The resulting 7-(6'-*methoxy*-1'-*naphthoyl*)-4-*methylhydrindene* (III) smoothly underwent the Elbs dehydration to 3-*methoxy*-20-*methylcholanthrene* (IV) when heated for 20 minutes at 405°.



(I.) (II.) (III.) (IV.) *

The same modification of the original method of Fieser and Seligman was likewise found preferable for the synthesis of 20-methylcholanthrene, in which case the lithio-compound (I) was condensed with 1-naphthonitrile. The methoxy-compound (IV) was demethylated by hydrobromic acid in boiling acetic acid, giving 3-*hydroxy*-20-*methylcholanthrene*,† which was purified through its acetate. Robertson's procedure (J., 1930, 1136) was followed for the preparation of the glucoside of this phenol, its potassium salt being condensed in aqueous acetone solution with *O*-tetra-acetyl-α-glucosidyl bromide. The resulting 3-O-*tetra-acetyl*-β-*glucosidoxy*-20-*methylcholanthrene* was deacetylated with cold methyl-alcoholic ammonia, but the free glucoside was amorphous and could not be obtained crystalline or analytically pure. It was, however, completely insoluble in water. 4'-O-*Tetra-acetyl*-β-*glucosidoxy*-3 : 4-*benzpyrene* (V) was similarly prepared, and in this case also the free glucoside was amorphous and insoluble in water.



(V.)

In the hope of overcoming this lack of solubility by the introduction of a salt-forming carboxyl group preliminary experiments have been made on the condensation of 4'-hydroxy-3 : 4-benzpyrene with methyl α-triacetylbromo-*d*-galacturonate (Morell, Baur, and Link, *J. Biol. Chem.*, 1935, **110**, 719). The product of this reaction has not yet been obtained analytically pure. Unsuccessful attempts have also been made to prepare the succinic half-esters of 3-hydroxy-20-methylcholanthrene and 4'-hydroxy-3 : 4-benzpyrene.

While these experiments on the production of water-soluble derivatives were in progress the free hydroxy-compounds and also their methyl ethers were submitted to tests for carcinogenic activity, with the somewhat surprising result that all four compounds were found completely devoid of activity (Bachmann *et al.*, *Proc. Roy. Soc.*, 1937, *B*, **123**, 343). The following table, giving the duration of the mouse-painting experiments, supplements the report already published. No tumour has beeen obtained in any mouse.

Compound.	No. of mice.	Duration of experiment (days).
3-Hydroxy-20-methylcholanthrene	10	549
3-Methoxy-20-methylcholanthrene	10	406
4'-Hydroxy-3 : 4-benzpyrene	10	434
4'-Methoxy-3 : 4-benzpyrene	10	444

The lack of carcinogenicity of the hydroxy-compounds defeats the original purpose of transforming them into water-soluble derivatives. Whether the loss of activity is due to the position or to the nature of the hydroxyl group or to both these factors cannot

* The sterol system of numbering used by Fieser and Seligman (*J. Amer. Chem. Soc.*, 1935, **57**, 1377) for denoting the positions of substituents in the cholanthrene molecule; the numbers 18, 19, and 21 are assigned to methyl groups.

† Publication of our work at the present stage is desirable in spite of the fact that the primary object of the investigation has not yet been achieved, because Professor Fieser has very courteously informed us that he and Dr. Riegel have also synthesised this hydroxymethylcholanthrene by substantially the same method that we have employed.

be inferred from the data at present available, but it is certain that the introduction of oxygen does not *necessarily* lead to loss of carcinogenic activity, as is shown by the production of tumours by 9-methoxy-1 : 2 : 5 : 6-dibenzanthracene (Barry *et al.*, *ibid.*, 1935, *B*, **117**, 318) and by 3-hydroxy-1 : 2-benzanthracene and its methyl ether (Fieser, Hershberg, Long, and Newman, *J. Amer. Chem. Soc.*, 1937, **59**, 475). Hence we propose to continue our search for potent carcinogenic hydroxy-compounds which may serve as a basis for the production of water-soluble derivatives.

The ultra-violet absorption spectra of 3-hydroxy-20-methylcholanthrene and its methyl ether have been determined by Dr. E. Roe, and are in accord with the structures of substituted 1 : 2-benzanthracenes assigned to these compounds.

Experimental.

6-*Methoxy*-1-*naphthonitrile* (II).—In the preparation of this compound from the corresponding diazonium salt better yields were obtained with nickel cyanide than with cuprous cyanide, the procedure being based on that of McRae (*J. Amer. Chem. Soc.*, 1930, **52**, 4550), adapted from the method of Korczynski and Fandrich (*Compt. rend.*, 1926, **183**, 421).

A suspension of 6-methoxy-1-naphthylamine sulphate (Cohen, Cook, and Hewett, J., 1934, 656; 1935, 451) (15 g.) in water (200 c.c.) and concentrated hydrochloric acid (30 c.c.) was diazotised at 0° with sodium nitrite (4 g. in 60 c.c. of water). The resulting solution was added during ½ hour to a well-stirred ice-cold solution of nickel cyanide (75 c.c.) covered with a layer of benzene. The cyanide solution was prepared by addition of a solution of pure nickel nitrate (36·5 g.) in water (60 c.c.) to a solution of potassium cyanide (40·7 g.) and sodium hydroxide (10 g.) in water (140 c.c.). The mixture was stirred at 0° for a further ½ hour, then allowed to warm to room temperature, and finally, after 1½ hours, heated to 50° and maintained at this temperature for ½ hour. The liquid was filtered, and the tarry residue extracted several times with warm benzene. The extract was dried and distilled; the 6-methoxy-1-naphthonitrile (b. p. 154°/0·3 mm.) crystallised from ligroin in colourless prisms (35% yield), m. p. 78—79°, in agreement with Butenandt and Schramm (*loc. cit.*) (Found: C, 78·9; H, 5·1. Calc.: C, 78·7; H, 4·9%).

7-(6′-*Methoxy*-1′-*naphthoyl*)-4-*methylhydrindene* (III).—A solution of 7-bromo-4-methylhydrindene (Fieser and Seligman, *J. Amer. Chem. Soc.*, 1935, **57**, 942) (4·2 g.) in anhydrous ether (30 c.c.) was added during an hour, with repeated shaking, to a suspension of powdered lithium (0·4 g.) in anhydrous ether (25 c.c.) kept under nitrogen. Reaction was completed by 6 hours' boiling, and a solution of 6-methoxy-1-naphthonitrile (3·6 g.) in ether (25 c.c.) and benzene (15 c.c.) was slowly added to the ice-cold solution of the lithium compound (I). The whole was boiled for 24 hours, and the product decomposed with ice. In order to hydrolyse the ketimine primarily formed in this reaction the material from the ethereal layer was refluxed for 2 hours with 10% hydrochloric acid, and re-extracted with ether and distilled. The *ketone* (III) (3·1 g., b. p. 245—250°/1 mm.) crystallised from alcohol in large colourless prisms, m. p. 86—87° (Found: C, 83·5; H, 6·4. $C_{22}H_{20}O_2$ requires C, 83·4; H, 6·3%).

3-*Methoxy*-20-*methylcholanthrene* (IV).—The aforesaid ketone (3 g.) was heated at 405° for 20 minutes in an atmosphere of carbon dioxide, and the residue distilled in a vacuum (b. p. 240—245°/0·3 mm.). The orange crystalline distillate (2·3 g.) was treated, in benzene solution, with picric acid, and gave purplish-black prisms of the picrate of 3-methoxy-20-methylcholanthrene, m. p. 178—179°. This picrate was freed from picric acid by shaking with ether and aqueous ammonia. The resulting 3-*methoxy*-20-*methylcholanthrene* (IV) (1 g.) crystallised from benzene–alcohol in light straw-coloured needles, m. p. 165—166·5° (corr.) (Found: C, 88·7; H, 6·2; OMe, 9·8. $C_{22}H_{18}O$ requires C, 88·55; H, 6·1; OMe, 10·4%).

3-*Hydroxy*-20-*methylcholanthrene*.—For demethylation, a suspension of the methoxy-compound (IV) (1·65 g.) in glacial acetic acid (40 c.c.) and hydrobromic acid (*d* 1·48; 17 c.c.) was boiled for 3 hours, during which a clear solution was obtained. The product was precipitated with water, collected, recrystallised from glacial acetic acid (charcoal), and then acetylated by warming for 5 minutes with acetic anhydride (2 c.c.) in pyridine (4 c.c.). 3-*Acetoxy*-20-*methylcholanthrene* crystallised from ethyl acetate in straw-coloured rhombs, m. p. 191—192° (corr.) (Found: C, 84·9; H, 5·7. $C_{23}H_{18}O_2$ requires C, 84·6; H, 5·6%). For hydrolysis a suspension of this acetate (0·75 g.) in alcohol (40 c.c.) and 50% aqueous potassium hydroxide (1 c.c.) was boiled for 3 minutes in an atmosphere of nitrogen. The orange solution was diluted with water and acidified with hydrochloric acid, and the

precipitate dried and recrystallised from methyl alcohol–benzene. *3-Hydroxy-20-methylcholanthrene* (0·45 g.) formed golden-yellow leaflets, m. p. 218·5—220° (corr.) in a bath preheated to 200° (Found: C, 88·4; H, 5·8. $C_{21}H_{16}O$ requires C, 88·7; H, 5·7%).

3-O-*Tetra-acetyl*-β-*glucosidoxy-20-methylcholanthrene*.—O-Tetra-acetyl-α-glucosidyl bromide (0·4 g.) was added to a solution of 3-hydroxy-20-methylcholanthrene (0·3 g.) in acetone (10 c.c.) and 12% aqueous potassium hydroxide (2 c.c.). Further quantities of the bromide (0·4 g.) and 12% potash (2 c.c.) were added after 16 hours at room temperature, and the whole kept for another 2 days. The *tetra-acetyl glucoside* was collected and recrystallised from alcohol, forming pale yellow needles, m. p. 210—211° (Found: C, 67·9; H, 5·6. $C_{35}H_{34}O_{10}$ requires C, 68·4; H, 5·6%).

4′-O-*Tetra-acetyl*-β-*glucosidoxy*-3 : 4-*benzpyrene* (V).—The 4′-hydroxy-3 : 4-benzpyrene was prepared by sulphur-dehydrogenation of 4′-keto-1′ : 2′ : 3′ : 4′-tetrahydro-3 : 4-benzpyrene (Fieser, Hershberg, and Newman, *J. Amer. Chem. Soc.*, 1935, **57**, 1509) and purified through its acetate. The hydroxy-compound (1 g.) in acetone (15 c.c.) and water (5 c.c.) was twice treated with potassium hydroxide (0·2 g.) and O-tetra-acetyl-α-glucosidyl bromide (1·5 g.), with an interval of 24 hours. After a second 24 hours the pale yellow silky needles of the *tetra-acetyl glucoside* (V) were collected and recrystallised from alcohol (yield, 0·4 g.); they then had constant m. p. 184—185° (Found: C, 68·3; H, 5·2. $C_{34}H_{30}O_{10}$ requires C, 68·2; H, 5·1%). For deacetylation to the free glucoside a suspension of this tetra-acetate in saturated methyl-alcoholic ammonia was kept in the ice-chest for 36 hours. The flocculent precipitate was collected and dissolved in hot alcohol, and the solution cooled. The glucoside, not obtained pure, separated as a gelatinous precipitate which dried to a greenish-yellow powder, m. p. 270—273° (Found: C, 70·5; H, 5·7. $C_{26}H_{22}O_6$ requires C, 72·5; H, 5·2%).

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Research Institute of the Royal Cancer Hospital (Free), London, S.W. 3. [*Received, October 18th*, 1937.]

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386. *The Constitution of Complex Metallic Salts. Part VI. The Constitution of the Phosphine and Arsine Derivatives of Silver and Aurous Halides. The Configuration of the Co-ordinated Argentous and Aurous Complex.*

By Frederick G. Mann, Alexander F. Wells, and Donald Purdie.

It is shown that the trialkyl-phosphine and -arsine derivatives of silver iodide possess four-fold macro-molecules, $[R_3P(As)\rightarrow AgI]_4$, which have the same structure and configuration as the cuprous iodide derivatives previously described. It follows that the 4-covalent argentous complex is tetrahedral, and that the 3-covalent iodine atom can be regarded as being at one apex of a tetrahedron with its three valencies directed towards the remaining apices. The phosphine and arsine derivatives of the aurous halides are, however, unimolecular, $[R_3P(As)\rightarrow AuX]$, and the 2-covalent aurous complex is probably linear. The phosphine–gold compounds are remarkably stable and can be distilled without decomposition. The electronic significance of the results is discussed.

We have already shown (J., 1936, 1503) that the trialkyl-phosphine and -arsine derivatives of cuprous iodide, previously considered to be $R_3P(As),CuI$, possess a four-fold macro-molecule, $[R_3P(As)\rightarrow CuI]_4$, and must therefore be termed tetrakis-[iodotrialkylphosphine(or arsine)copper]. A complete X-ray examination of the triethylarsine member, $[Et_3As\rightarrow CuI]_4$, showed that the four copper atoms occupy the apices of a regular tetrahedron; the iodine atoms are situated each above the central point of one face of this tetrahedron, so that they also form a tetrahedron external to

that of the copper atoms. Beyond each copper atom is an arsenic atom lying on the elongation of the axis joining the centre of the inner tetrahedron to the copper atom. The iodine atoms are thus 3-covalent, each being joined to the three neighbouring copper atoms apparently by one covalent and two co-ordinate links. Two important stereochemical results follow: (1) the 4-covalent cuprous atom has a tetrahedral configuration, and since each is joined by a covalent link to one iodine and by co-ordinate links to one arsenic and two iodine atoms, it acquires 7 electrons and so attains the electronic state of krypton; (2) the stereochemistry of the 3-covalent iodine atom must be similar to that of the 3-covalent sulphur atom, *i.e.*, the iodine atom occupies one apex of a tetrahedron with its valencies directed towards the other three apices. This is the first available evidence for the stereochemistry of 3-covalent iodine. Furthermore, it was shown that each co-ordinated arsenic atom lies at the centre of a tetrahedron, the apices of which are occupied by one cuprous atom and three carbon atoms.

The corresponding silver iodide derivatives, which are readily formed when the phosphine or arsine is shaken with silver iodide dissolved in concentrated aqueous potassium iodide solution, have now been investigated and prove also to possess a four-fold macro-molecule, $[R_3P(As)\rightarrow AgI]_4$, identical in chemical structure with the corresponding cuprous derivatives. This is indicated by their molecular weights in various solvents (Table I), and conclusively proved by a comparison of the crystal structure of the cuprous and the argentous compounds. Thus, whereas $[Et_3As\rightarrow CuI]_4$ is cubic, the *compound* $[Et_3As\rightarrow AgI]_4$ is tetragonal, and its space-group is the sub-group (or tetragonal equivalent) of the cubic space-group of the cuprous compound: it follows that the structure of $[Et_3As\rightarrow AgI]_4$ is merely a distorted version of that of $[Et_3As\rightarrow CuI]_4$. The *compound* $[Pr^{a}_3As\rightarrow AgI]_4$ is, however, strictly isomorphous with $[Et_3As\rightarrow CuI]_4$, the effects of the replacement of the cuprous by the argentous atom and of the ethyl by the *n*-propyl group being compensatory. This remarkable, and probably unique, example of isomorphism shows without doubt that the cuprous and argentous compounds have identical chemical structures. It follows that the 4-covalent argentous atom has also a tetrahedral configuration, in confirmation of the results of Cox, Wardlaw, and Webster (J., 1936, 775), and that the argentous atoms in the above compounds, by acquiring 7 electrons, attain the electronic structure of xenon. It is rather surprising that silver should build up the macro-molecule in order to obtain a covalency of 4 instead of forming the simple 2-covalent compound $[R_3P(As)\rightarrow AgI]$, because whereas in the complex cyanides the cuprous atom shows a co-ordination number of 2 or 4 (as in $K[Cu(CN)_2]$ and $K_3[Cu(CN)_4]$ respectively), the argentous atom shows only a co-ordination number of 2 (as in $K[Ag(CN)_2]$) and does not apparently form compounds such as $K_3[Ag(CN)_4]$. It should be emphasised that the crystallographic evidence shows conclusively that the phosphine- and arsine-silver compounds exist as four-fold macro-molecules in the solid state: since, however, the molecular weights in various organic solvents (Table I) usually indicate an association of 3—4 $[R_3P(As)\rightarrow AgI]$ units, it is possible that in these solvents the four-fold molecule does undergo partial dissociation. Similar results were obtained for the molecular weights of the cuprous compounds (*loc. cit.*).

It is noteworthy that, whereas the m. p.'s of the homologous $[R_3P(As)\rightarrow CuI]_4$ compounds fall as each series is ascended, no such regularity occurs in the $[R_3P(As)\rightarrow AgI]_4$ compounds, where the m. p. in each series rises from the ethyl to the *n*-propyl member and then falls markedly to the *n*-butyl member, which in the arsine series is liquid at room temperature. The argentous, unlike the cuprous, compounds do not apparently react with αα'-dipyridyl: furthermore, they are stable towards air and light. When heated in a vacuum they behave similarly to the cuprous compounds, decomposing into silver iodide and the free phosphine or arsine.

The corresponding aurous compounds, *e.g.*, $[R_3P(As)\rightarrow AuCl]$, are best prepared by the method of Cahours and Gal (*Compt. rend.*, 1870, **70**, 1380; **71**, 208), a cooled aqueous-alcoholic solution of chloroauric acid being shaken with 2 equivs. of the phosphine or arsine: it is probable that in these circumstances an auric derivative of 1 equiv. of the phosphine or arsine is first formed, and then rapidly undergoes reduction by the second

equiv. to give the required compound. Derivatives of the alkyl sulphides, *e.g.*, *monochlorodiethylsulphidegold*, [Et_2S→AuCl], are similarly prepared. It has now been found that if the chloroauric acid solution is first treated with excess potassium iodide

TABLE I.

*Molecular complexity of the phosphine and arsine derivatives of silver and aurous halides in various solvents.**

(The values given are those of *n* in the formulæ [R_3P(As)→AgI]$_n$ and [R_3P(As)→AuX]$_n$ at the lowest concentration measured. For values at higher concentrations, see Experimental.)

Silver compounds.

	M. p.	$COMe_2$.	C_6H_6.	$C_2H_4Br_2$.
[Et_3P,AgI]	208—209°	3·70	3·40	3·88
[Pr^a_3P,AgI]	258—265		3·78	3·38
[Bu^a_3P,AgI]	43		4·21	3·54
[Et_3As,AgI]	182—185		3·56	4·04
[Pr^a_3As,AgI]	219—221		3·33	3·62

Aurous compounds.

	M. p.	$COMe_2$.	C_6H_6.	$C_2H_4Br_2$.	$CHBr_3$.
[Et_3P,AuCl]	78°		1·32	1·13	1·15
[Et_3P,AuI]	67		1·25	1·09	1·02
[Pr^a_3P,AuCl]	40		1·20	1·12	1·14
[Me_3As,AuCl]	decomp.	1·11			
[Me_3As,AuI]	176—178	1·13			
[Me_3As,AuSCN]	127—128	1·11			
[Et_3As,AuCl]	94—95		1·34	1·05	1·03
[Et_3As,AuI]	77		1·18	1·06	1·10
[Et_2S,AuCl]	38—40	1·01		1·09	1·10

* Determinations in acetone are ebullioscopic, the others cryoscopic.

or thiocyanate, the corresponding *compounds* [R_3P(As)→AuI] and [R_3P(As)→AuSCN] are formed. All the aurous compounds studied, however, proved to have the simple unimolecular formula. So striking is the difference between these aurous compounds and the cuprous and argentous compounds that extensive determinations of the molecular weights of a variety of aurous compounds were made in various solvents (Table I): the evidence throughout showed that the aurous compounds had the unimolecular formula, a result which has been confirmed crystallographically. Levi-Malvano (*Atti R. Accad. Lincei*, 1908, **17**, 857) found that the compounds [$(MeO)_3P$→AuCl] and [Ph_3P→AuCl] also gave normal molecular weights in freezing benzene. It follows that the gold in all the above compounds, as in the well-known K[$Au(CN)_2$], shows a true co-ordination number of 2.

Considerable interest attaches to the structure of these aurous compounds, as there is very little evidence available for the configuration of 2-co-ordinate metallic complexes generally. Unfortunately, it has not been possible to elucidate the complete crystal structure of any of these compounds, although the four isomorphous ethyl members, [Et_3P(As)→AuCl] and [Et_3P(As)→AuI], have been examined in detail. These four compounds crystallise in the monoclinic system with space group $P2_1$, there being 4 simple molecules in the unit cell. The absence of a centre of symmetry in the projection along the ***a*** axis, together with the large number of parameters, makes a complete determination of the structure difficult, but the positions of the gold atoms have been fixed from Patterson–Fourier projections, and the structure shown in Fig. **3**, based on the packing of linear molecules of [Et_3As→AuCl], is suggested as being in accord with the available data.

The phosphine–gold compounds, [R_3P→AuCl(I)], possess remarkable stability and may be distilled without decomposition at low pressures. The *n*-butyl chloro-compound is a liquid at room temperature and can be volatilised even at atmospheric pressure: if the vapour is passed through a heated tube, decomposition occurs with formation of a fine film of metallic gold. The arsine–gold compounds, [R_3As→AuCl(I)], are very much less stable, and merely on exposure to light slowly decompose with deposition of metallic gold.

It is noteworthy that, although gold differs so markedly from copper and silver in the above compounds, yet the "unimolecular" condition of these gold derivatives brings the metal electronically in line with mercury and thallium, *i.e.*, with neighbouring metals in the same series. Thus the gold atom, having originally 2, 8, 18, 32, 18, 1 electrons, gains 3 electrons in compounds such as [Et_3P→AuCl]. Mercury (2, 8, 18, 32, 18, 2) is remarkable for the stability of its 2-covalent compounds, such as HgR_2 and $Hg(SR)_2$, in all of which the metal acquires 2 electrons: it is significant that the molecules of the mercapto-compounds do not co-ordinate with one another through the sulphur atoms to

increase further the mercury electrons, although those of the palladium mercaptans, $Pd(SR)_2$, readily do so (Mann and Purdie, J., 1935, 1549; Wells, *Z. Krist.*, 1937, **96**, 435). In the case of thallium (2, 8, 18, 32, 18, 3), the thallous alkyls TlR are unknown, and thallic alkyls, TlR_3, are difficult to prepare and exceedingly reactive (Groll, *J. Amer. Chem. Soc.*, 1930, **52**, 2998), the normal stable alkyl derivatives being true salts of the type $[TlR_2]X$, in which the metal gains 1 electron. It is clear, therefore, that for all three metals a group of 4 shared electrons in the 6th quantum group permits considerable stability.

Compounds of all these metals are, however, known in which the metal attains the electronic state of radon, but those of aurous gold and thallium are rare. Thus gold in the compounds $[(NH_3)_3AuCl]$ (Meyer, *Compt. rend.*, 1906, **143**, 280), $[(NH_3)_2Et_3PAuCl]$, and $[(NH_3)_2(MeO)_3PAuCl]$ (Levi-Malvano, *loc. cit.*), all of which are stable at room temperature, shows a co-ordination number of 4 and a gain of 7 electrons: mercury in the complex cyanides, *e.g.*, $K_2[Hg(CN)_4]$ acquires 6 electrons: thallium tribromide combines with the quaternary pyridinium bromides to give compounds such as $[C_5H_5N{\cdot}Bu^a][TlBr_4]$, in which thallium gains 5 electrons (Krause and von Grosse, *Ber.*, 1926, **59**, 1712).

An aurous chloride derivative of an unsymmetrical phosphine, $[R_1R_2R_3P{\rightarrow}AuCl]$, will be stereochemically parallel to an unsymmetrical phosphinimine, $R_1R_2R_3P{\rightarrow}N{\cdot}SO_2{\cdot}C_7H_7$ (Mann and Chaplin, this vol., p. 527), and experiments are now in progress to resolve both classes into optically active forms.

Experimental.

Chemical Data.

The names of the solvents used for recrystallising the compounds are given in parentheses immediately after the names of the compounds concerned. All molecular weights were determined cryoscopically except those in acetone, which were ebullioscopic.

Tetrakis(monoiodotrialkylphosphinesilver), $[R_3P{\rightarrow}AgI]_4$.—All members were prepared by the same method, which is therefore given in detail only for the *ethyl* compound. Freshly distilled triethylphosphine (6 g.) was shaken with a solution of silver iodide (13·2 g., 1·1 mols.) in saturated aqueous potassium iodide solution (50 c.c.) for 2 hours, a white solid, not apparently wetted by water, rapidly separating. This was collected, washed with potassium iodide solution and water in turn, and dried. The crystals (acetone) have m. p. 208—209° with preliminary softening, and are soluble in most organic liquids (Found: C, 20·5; H, 4·4; *M*, in 5·213% acetone solution, 1300; in 9·432%, 1390; in 4·688% benzene solution, 1200; in 9·307%, 1240; in 13·44%, 1190; in 1·508% ethylene dibromide solution, 1367. $C_{24}H_{60}I_4P_4Ag_4$ requires C, 20·4; H, 4·3%; *M*, 1412).

The n-*propyl* compound (acetone), when placed in a sealed tube in an oil-bath at 220° and rapidly heated, melted at 258—265° to a clear liquid; it is less soluble generally than the ethyl compound [Found: C, 27·4; H, 5·3; *M*, in 4·329% benzene solution, 1490; in 2·059% ethylene dibromide solution, 1340 (slight turbidity appeared in the latter solution). $C_{36}H_{84}I_4P_4Ag_4$ requires C, 27·3; H, 5·4%; *M*, 1580].

The n-*butyl* compound separated in a viscous form which on exposure to air soon solidified; from a hot concentrated alcoholic solution it separated on cooling as a fine emulsion which, on being stirred, rapidly crystallised. The crystals, m. p. 43°, were much more soluble than the propyl compound in most liquids [Found: C, 32·9; H, 6·26; AgI (direct ignition), 53·7; *M*, in 6·077% benzene solution, 1840; in 1·444% ethylene dibromide solution, 1550; in 2·856%, 1630; in 4·112%, 1700. $C_{48}H_{108}I_4P_4Ag_4$ requires C, 33·0; H, 6·22; AgI, 53·7%; *M*, 1748].

Tetrakis(monoiodotrialkylarsinesilver), $[R_3As{\rightarrow}AgI]_4$.—These were prepared precisely as the phosphine compounds. The *ethyl* compound (acetone), when heated in a sealed tube with rapid preliminary heating, has m. p. 182—185° (Found: C, 18·1; H, 3·7; *M*, in 5·247% benzene solution, 1410; in 10·17%, 1390; in 1·877% ethylene dibromide solution, 1600. $C_{24}H_{60}I_4Ag_4As_4$ requires C, 18·1; H, 3·8%; *M*, 1587).

The n-*propyl* compound (acetone), rapidly heated in a sealed tube, has m. p. 219—221° (decomp.) (Found: C, 24·8; H, 4·8; AgI, 53·5; *M*, in 6·204% benzene solution, 1460; in 10·91%, 1460; in 1·655% ethylene dibromide, 1590. $C_{36}H_{84}I_4Ag_4As_4$ requires C, 24·6; H, 4·8; AgI, 53·5%; *M*, 1756). The *n*-butyl compound is an oil at room temperature and was not further investigated.

All the above silver compounds form colourless crystals, and all are apparently decomposed

by cold bromoform. The arsine members are the least stable, and decompose when boiled with most organic liquids; decomposition is slowest in boiling acetone, which for crystallisation purposes should be heated rapidly on a water-bath and not directly, the solution being filtered immediately before cooling.

Monohalogenotrialkylphosphinegold, [$R_3P \rightarrow AuX$].—The method of preparation is similar for all the gold compounds, and is given in detail for the chlorotriethylphosphine compound only. To prepare the corresponding iodo- or thiocyanato-compounds, the chloroauric acid solution is first treated with a concentrated aqueous solution of 6 equivs. of potassium iodide or thiocyanate respectively, and the mixture cooled before dilution with alcohol; after addition of the alcoholic phosphine or arsine solution, the mixture should be vigorously shaken until no coloured product remains. For all preparations, an aqueous solution of chloroauric acid, $HAuCl_4$, containing 20% of gold was used. All the following gold compounds were colourless when pure.

Monochlorotriethylphosphinegold was prepared by cautiously adding a solution of freshly distilled triethylphosphine (5 g., 2 mols.) in alcohol (20 c.c.) to a well-cooled, agitated mixture of the chloroauric acid (20 c.c., 0·95 mol.) and alcohol (20 c.c.). An orange product first separated and was rapidly replaced by the required white solid. The mixture was shaken for 1 hour, diluted with water (50 c.c.), and the white product collected, washed with water, and dried. Cooling and (in particular) the presence of alcohol appear to be essential for such preparations. The chloro-triethyl compound (alcohol) has m. p. 78°, b. p. 210°/0·03 mm., subliming slightly before boiling (Found: C, 20·5; H, 4·4; *M*, in 3·932% benzene solution, 463; in 7·504%, 532; in 1·682% ethylene dibromide solution, 395; in 3·586%, 433; in 1·632% bromoform solution, 402. Calc. for $C_6H_{15}ClAuP$: C, 20·5; H, 4·3%; *M*, 351). Cahours and Gal (*loc. cit.*) prepared this compound and its arsine analogue: all the other gold compounds are new.

Monoiodotriethylphosphinegold (alcohol) had m. p. 67°, b. p. 195—200°/0·03 mm. (Found: C, 16·55; H, 5·6; *M*, in 5·327% benzene solution, 555; in 10·69%, 662; in 1·923% ethylene dibromide solution, 484; in 3·723%, 524; in 1·573% bromoform solution, 450. $C_6H_{15}IAuP$ requires C, 16·3; H, 3·4%; *M*, 442). The thiocyanato-analogue was obtained as an uncrystallisable liquid and was not further investigated.

Monochlorotri-n-*propylphosphinegold* separated as a liquid which crystallised after many days' standing; it is freely soluble in all organic liquids tried(16) except *cyclo*hexane and petrol. It was recrystallised from a small quantity of alcohol, a fine emulsion first forming and rapidly crystallising on cooling; m. p. 40°, b. p. 205—207°/0·04 mm. (Found: C, 27·8; H, 5·6; *M*, in 4·563% benzene solution, 472; in 9·139%, 557; in 1·866% ethylene dibromide solution, 440; in 3·826%, 458; in 5·732%, 474; in 1·509% bromoform solution, 448. $C_9H_{21}ClAuP$ requires C, 27·5; H, 5·4%; *M*, 393).

The n-*butyl* homologue separated as an oil which did not crystallise. It was extracted with chloroform, and the extract washed with water, dried (sodium sulphate), filtered, and the solvent evaporated. The residual oil when distilled gave a first fraction, b. p. 110°/0·05 mm., which on cooling gave white deliquescent crystals, presumably of the phosphine oxide, and a higher fraction, b. p. 218—225°/0·025 mm., as a viscous colourless liquid. The latter on refractionation gave the required compound as a colourless liquid, b. p. 215—225°/0·03 mm. (Found: C, 33·3; H, 6·4. $C_{12}H_{27}ClAuP$ requires C, 33·1; H, 6·3%).

Monoiodotri-n-*butylphosphinegold* also separated as an oil, which on distillation gave the same crystalline first fraction, followed by a pale green (almost colourless) fraction, b. p. 220—225°/0·2 mm., of the pure liquid compound (Found: C, 27·7; H, 5·3. $C_{12}H_{27}IAuP$ requires C, 27·4; H, 5·2%). On one occasion this oil crystallised on standing, and its m. p. is probably about room temperature.

Monohalogenotrialkylarsinegold, [$R_3As \rightarrow AuX$].—Owing to the comparative instability of these arsine compounds, gold could be estimated by direct ignition. *Monochlorotrimethylarsinegold* (acetone), m. p. 165—175° (decomp.), on exposure to air slowly became purple and ultimately deposited gold (Found: C, 10·55; H, 2·6; Au, 55·8; *M*, in 3·330% acetone solution, 393. $C_3H_9ClAsAu$ requires C, 10·2; H, 2·6; Au, 55·9%; *M*, 352·7). The corresponding *iodo*-compound (acetone) had m. p. 176—178° (decomp., with preliminary darkening) (Found: C, 7·95; H, 2·0; Au, 44·1; *M*, in 3·036% acetone solution, 501. C_3H_9IAsAu requires C, 8·1; H, 2·0; Au 44·4%; *M*, 444); and the *thiocyanato*-analogue (alcohol or acetone), when rapidly heated had m. p. 127—128° (decomp.) (Found: C, 12·9; H, 2·5; N, 3·7; Au, 52·65; *M*, in 3·715% acetone solution, 415; in 6·610%, 440. $C_4H_9NSAsAu$ requires C, 12·8; H, 2·4; N, 3·7; Au, 52·6%; *M*, 375).

Monochlorotriethylarsinegold (carbon tetrachloride or acetone) had m. p. 94—95° (followed by decomp.) (Found: Au, 49·8; *M*, in 2·963% benzene solution, 529; in 5·653%, 656; in 7·295%, 707; in 1·380% ethylene dibromide solution, 414; in 2·766%, 449; in 0·9228% bromoform solution, 406; in 2·046%, 440. Calc. for $C_6H_{15}ClAsAu$: Au, 50·0%; *M*, 395). The *iodo-compound* (alcohol), m. p. 77° (slight decomp.), gives in carbon tetrachloride a green solution which becomes colourless on dilution with alcohol; crystals separating from the undiluted solution are also green, but become colourless on exposure to air (Found: C, 14·6; H, 3·3; Au, 40·1; *M*, in 3·267% benzene solution, 573; in 6·784%, 730; in 1·664% ethylene dibromide solution, 517; in 3·243%, 559; in 1·231% bromoform solution, 534; in 2·398%, 561. $C_6H_{15}IAuP$ requires C, 14·8; H, 3·1; Au, 40·5%; *M*, 486).

The gold derivatives of the higher alkylarsines appear to be liquid at room temperature. None of the above gold compounds apparently reacts with αα'-dipyridyl.

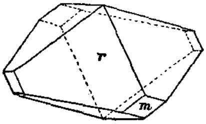
Monochlorodiethylsulphidegold separated first as a colourless oil which on chilling crystallised. It is unstable on exposure to light, and soluble in most organic liquids; the crude product was rapidly dried, dissolved in a minimum of acetone or (better) methyl ethyl ketone, and the solution filtered, chilled in ice-water, and largely diluted with pure petrol (b. p. 40—50°). A fine emulsion formed, and was rapidly replaced by fine colourless crystals. These were collected, dried, and investigated without delay; m. p. 38—40° (slight decomp.) [Found: C, 15·1; H, 3·3; Au (direct ignition), 61·20; *M*, in 4·646% acetone solution, 325; in 1·596% ethylene dibromide solution, 352; in 1·210% bromoform solution, 356. $C_4H_{10}ClSAu$ requires C, 14·9; H, 3·1; Au, 61·1%; *M*, 322·8].

Crystallographic Data.

Tetrakis(*monoiodotriethylphosphinesilver*).—Rhombic crystals, usually prisms elongated along the *a* axis, with the forms {100}, {010} and {001}. The approximate cell dimensions are: *a* = 10·9, *b* = 20·8, *c* = 20·0 A., and for a density of 2·05 the cell contains 16 [$Et_3P \rightarrow AgI$] components. The halvings observed are: *0kl*, *k* even; *h0l*, *h* even; *hk*0, *h* + *k* even. The space group is *P ban*. The reflexions on a Weissenberg photograph about the *a* axis could be indexed for a cell having *b* = 10·4, *c* = 20·0 A., since 0*kl* reflexions occur only with *k* even, and furthermore only the fourth and the eighth order from (010) are observed. This pseudo-cell has almost exactly the same dimensions as the tetragonal cell of [$Et_3As \rightarrow AgI]_4$, showing that the structures of the two compounds are closely related.

FIG. 1.

Tetrakis(*monoiodotri*-n-*propylphosphinesilver*).



Tetrakis(*monoiodotri*-n-*propylphosphinesilver*).—Well-developed tetragonal crystals showing the forms *m*{110} and *r*{101} (Fig. 1). This is the tetragonal equivalent of the dodecahedral development of the cubic tetrakis(monoiodotri-*n*-propylarsinesilver). The dimensions of the unit cell are: *a* = 15·5, *c* = 12·3 A., and for 8 [$(C_3H_7)_3P \rightarrow AgI$] components in the unit cell the calculated density is 1·77. The lattice is body-centred. A Weissenberg photograph about an *a* axis shows only the fourth-order reflexion from the basal plane, but in view of the weakness of 202 and the absence of 402 and 602 (204, 404, and 604 are present), the quartering of 00*l* is not to be taken as a space-group absence. There are no halvings other than those due to the body-centring, so that the same considerations apply here as to the triethylarsine analogue, and the space-group is $I\,\bar{4}2m$ or $I\,\bar{4}m2$.

Tetrakis(*monoiodotriethylarsinesilver*).—Tetragonal crystals, the usual habit being bipyramids terminated by *c*(001). Oscillation photographs gave the following approximate cell dimensions (from layer line separations): *a* = 10·7, *c* = 19·7 A. The density of the crystals (determined by flotation) is 2·24, requiring 8 [$(C_2H_5)_3As \rightarrow AgI$] components in the unit cell. The symmetry of the oscillation photographs about the [001], [100], and [110] axes shows that the Laue symmetry is D_{4h}, and the halvings observed are those due to a body-centred lattice only. There are therefore five possible space-groups: *I* 42 (D_4^9), *I* 4/*mmm* (D_{4h}^{17}), *I* 4*mm* (C_{4v}^9), $I\,\bar{4}m2$ (D_{2d}^9) and $I\,\bar{4}2m$ (D_{2d}^{11}). As in the cuprous analogue, the unit cell contains two macro-molecules, and of the above space-groups the first three are improbable since they would require the macro-molecules to lie on 4-fold axes with point symmetry 42, 4/*mmm* or 4*mm* respectively. The probable space-group is therefore either $I\,\bar{4}m2$ or $I\,\bar{4}2m$, in each of which the point symmetry of the 2-fold positions is $\bar{4}2m$. Although the cell dimensions of this compound are quite different from those of the cubic copper analogue

(a = *13·08* A.), *there are in each case two macro-molecules in the body-centred cell, and the* symmetry of these complexes is $\bar{4}3m$ for $[(C_2H_5)_3As{\rightarrow}CuI]_4$ and $\bar{4}2m$ for $[(C_2H_5)_3As{\rightarrow}AgI]_4$.

Tetrakis(monoiodotri-n-*propylarsinesilver).*—Cubic crystals of dodecahedral habit, isomorphous with the ethyl-copper analogue; a = 14·4 A. The density is 1·94, hence there are 8 $[(C_3H_7)_3As{\rightarrow}AgI]$ components in the unit cell. This case of isomorphism is important in establishing the constitution of the silver compounds (see above).

Monochloro- and Monoiodo-triethylphosphine- and -triethylarsine-gold.—These four isomorphous compounds separate from acetone or alcohol as monoclinic crystals, usually tabular on (010) or (001) and elongated along the a axis. The birefringence is low, and the dispersion high. Twinning across the (001) plane was observed in monoiodotriethylarsinegold, this being shown by etch-pits and by X-ray photographs. A photograph about the normal to the plane (001) of such a twin is symmetrical about the equatorial line, giving the appearance of a b-axis photograph. When tested in liquid air the crystals showed an appreciable pyroelectric effect. Oscillation photographs and Weissenberg photographs about the a and b axes gave the following cell dimensions:

	a.	b.	c.	β.		a.	b.	c.	β.
$[Et_3P{\rightarrow}AuCl]$	7·05	18·9	7·61	73°	$[Et_3As{\rightarrow}AuCl]$	7·05	19·2	7·70	74°
$[Et_3P{\rightarrow}AuI]$	7·30	19·4	7·87	75	$[Et_3As{\rightarrow}AuI]$	7·17	19·7	8·00	75

The only halving is $0k0$ absent for k odd, and the space-group is accordingly $P\,2_1$, the holohedral group $P\,2_1/m$ being excluded on account of the pyroelectricity. The densities show that in each case there are 4 molecules in the unit cell. The molecules must occupy two sets of general positions, (xyz) $(\bar{x}, \frac{1}{2} + y, \bar{z})$, the screw diad axes separating similar atoms of each pair of molecules by $b/2$ = 9·6 A. Consequently four-fold macro-molecules like those of the cuprous and argentous analogues are not present in these crystals. This would also, of course, apply to the higher space-group $P\,2_1/m$.

The precise crystal structure of these compounds has not been determined, but the following account of monochlorotriethylarsinegold shows the essential features of the structure and establishes the important point that the crystals are built up of single, presumably linear, molecules.

Monochlorotriethylarsinegold. The unit cell contains four molecules of $[(C_2H_5)_3As{\rightarrow}AuCl]$, and in the space-group $P\,2_1$ the general position is 2-fold: (xyz), $(\bar{x}, \frac{1}{2} + y, \bar{z})$. A complete structure determination would therefore involve the evaluation of 18 parameters apart from those of the carbon atoms. The gold atoms were located first by means of Patterson–Fourier projections. Intensities estimated on Weissenberg photographs about the a and b axes were used to obtain F^2 projections in the directions of these axes, and showed the arrangement of gold atoms depicted in Fig. 2. The relation of the atoms to the screw diad axes in the [010] projection may be that shown in (a) or (b).

Owing to the large scattering power of the gold atoms, the main features of the a and b axis Weissenberg photographs are immediately accounted for. The $h0l$ reflexions are, in general, very weak when h is odd, though three small-angle reflexions (101, 102, $10\bar{1}$) have appreciable intensities. The above arrangement exactly halves the a axis, so the weaker $h0l$ reflexions with h odd are probably due to the lighter atoms. Further, the strongest reflexions in this zone are 200 and 201, and in Table II the value of F' (from visually estimated intensities) is compared with the contribution from the gold atoms, calculated for the parameters (0·05, y_1, 0·10) and (0·45, y_2, 0·10). The planes are arranged in order of increasing sin θ/λ.

TABLE II.

Plane.	f_{Au}.	F', obs.	Plane.	f_{Au}.	F', obs.	Plane.	f_{Au}.	F', obs.
001	3·2	31	300	0	14	$40\bar{1}$	1·2	18
100	0	0	$20\bar{2}$	1·2	15	205	3·2	52
002	1·2	18	004	3·2	65	005	4·0	60
201	4·0	85	204	1·2	23	$20\bar{4}$	4·0	53
200	3·2	85	$20\bar{3}$	3·2	58	$40\bar{2}$	3·2	34
202	3·2	58	401	3·2	58	206	4·0	29
$20\bar{1}$	1·2	17	402	4·0	59	006	3·2	21
003	1·2	23	400	1·2	11	$40\bar{3}$	4·0	37
203	1·2	40	403	3·2	35			

Similarly the alternations in intensity of the $0kl$ reflexions follow from the parameters of the gold atoms. For a given set of $0kl$ reflexions with a fixed value of l, the intensities show a greater or less degree of alternation according to whether k is odd or even, the nature and amount of this alternation being different in the various sets of reflexions. These data are summarised in the following table, which also shows the calculated contributions from the gold atoms.

Intensities of 0kl *Reflexions.*

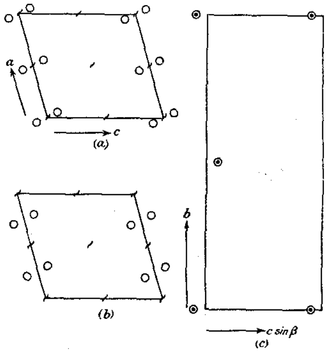
	f_{Au}.		
	k odd.	k even.	Observed intensity.
$0k1$	1·2	1·6	k odd $<$ k even
$0k2$	1·9	0·6	k odd $\gg$ k even
$0k3$	1·9	0·6	k odd $\gg$ k even
$0k4$	1·2	1·6	Very little alternation
$0k5$	0·0	2·0	k odd $<<<$ k even

It is important to establish the position of the gold atoms, since this proves conclusively that there is no complex formation in the crystal involving linkage between gold atoms, the closest approach between these atoms being $a/2 = 3·5$ A.

Examination of the packing of linear molecules of [$Et_3As\rightarrow AuCl$] shows that the probable structure is of the type shown in Fig. 3. To maintain reasonable interatomic

FIG. 2.

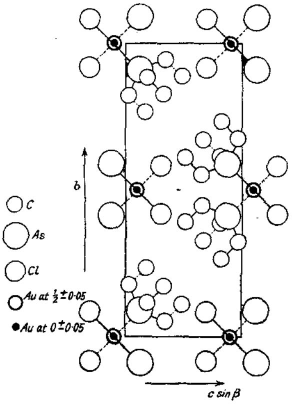
Arrangement of gold atoms in [$(C_2H_5)_3As\rightarrow AuCl$].



(*a*) *and* (*b*) *show the two possibilities for the projection along the* b *axis, and* (*c*) *the projection along the* a *axis.*

FIG. 3.

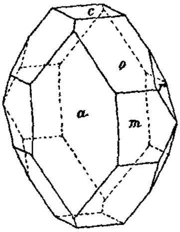
Suggested structure of [$(C_2H_5)_3As\rightarrow AuCl$], *viewed along the* a *axis.*



distances the molecules must be inclined at a considerable angle to the b axis, and in addition the molecules at $y = 0$ must be inclined to one another. Fig. 3 shows the structure viewed along the a axis. Full lines joining atoms indicate that these atoms lie above those joined by dotted lines, and ethyl groups are shown attached only to those arsenic atoms which lie within the unit cell. The corresponding [010] projection may be derived from Fig. 2 (*b*) which shows only the gold atoms. It should be emphasised that no attempt has been made to find the precise positions of the lighter atoms necessary to account for the weaker $h0l$ reflexions with h odd. In order to investigate the packing of the molecules some type of molecular model had to be adopted, and the following intramolecular distances were assumed: As–C, 1·95; Au–Cl, 2·25; Au–As, 2·40; the last two being taken as 10% less than the sum of the standard tetrahedral radii to allow for the 2-co-ordination of the gold atom. A knowledge of the lengths of the links in such a molecule would be of interest, but it was decided that these particular compounds are not suitable for an exact structure determination.

Monoiodotrimethylarsinegold. Orthorhombic crystals from acetone with the development shown in Fig. 4, the forms being *a*{100}, *m*{110}, *o*{111}, *r*{021}, and *c*{001}; also as pseudo-tetragonal prisms elongated along the *c* axis and terminated by the same faces. The development is pseudo-cubic except for the presence of (021) and the absence of (010), the angles 100 ∧ 111, 111 ∧ 001 and 111 ∧ 010 all being 54—55°. The crystal faces were not sufficiently perfect for exact measurement, but the development suggests the holohedral class *mmm*. The measured angles were: *am*, 45°; *om*, 36°; *cr*, 63°; all ±1°. The optics show that the symmetry is not higher than orthorhombic. The crystals, tested in liquid air, showed no signs of pyroelectricity, in contrast to the ethyl analogue.

FIG. 4.
Monoiodotrimethylarsinegold.



Oscillation photographs gave the following unit translations: $a = 12{\cdot}0$, $b = 11{\cdot}7$, $c = 11{\cdot}7$ A., all ±0·1 A. Photographs about the *a* and *b* axes show that the symmetry of the crystals is strongly pseudo-tetragonal; *e.g.*, 200 and 020 are very similar in intensity, whereas 002 is extremely weak. The pseudo-tetragonal axis is, however, the *c* and not the *a* axis as suggested by the cell dimensions. The halvings observed are: *hk*0, $h + k$ even, 0*kl*, *k* even, *h*0*l*, *l* even, indicating *Pbcn* (D_{2h}^{14}) as the space-group. The crystals have a density greater than 3·3, hence there are 8 molecules in the unit cell (*d*, calc.: 3·85). The molecules therefore occupy general positions (8-fold, *xyz*) without point symmetry. There is no 2-fold position in this space-group, showing that *four-fold macro-molecules do not exist in the crystals.*

Monothiocyanatotrimethylarsinegold.—Small tetragonal crystals. The cell dimensions are $a = 17{\cdot}3$, $c = 11{\cdot}9$ A., and for a density of 2·79 the unit cell contains 16 molecules. Oscillation photographs and a Weissenberg photograph about the *c* axis show the halvings characteristic of a body-centred lattice together with the following: 00*l*, $l = 4n$, *hh*0, *h* even, *h*0*l*, *h* and *l* even. The space group is therefore *I* 4*cd*, the molecules occupying the general 16-fold position without point symmetry.

The crystallographic data are summarised below.

Compound.	System.	*a*.	*b*.	*c*.	*β*.	*d*.	*n*.	Space-group.
$[Et_3P{\rightarrow}AgI]_4$	Rhombic	10·9	20·8	20·0	—	2·05	16	*P ban*
$[Pr_3P{\rightarrow}AgI]_4$	Tetragonal	15·5	15·5	12·3	—	1·77	8	$I\ \bar{4}2m$
								$I\ \bar{4}m2$
$[Et_3As{\rightarrow}AgI]_4$	Tetragonal	10·7	10·7	19·7	—	2·24	8	$I\ \bar{4}2m$
								$I\ \bar{4}m2$
$[Pr_3As{\rightarrow}AgI]_4$	Cubic	14·4	—	—	—	1·94	8	$I\ \bar{4}3m$
$[Et_3P{\rightarrow}AuCl]$	Monoclinic	7·05	18·9	7·61	73°	2·38	4	$P\ 2_1$
$[Et_3P{\rightarrow}AuI]$	„	7·30	19·4	7·87	75	2·71	4	$P\ 2_1$
$[Et_3As{\rightarrow}AuCl]$	„	7·05	19·2	7·70	74	2·60	4	$P\ 2_1$
$[Et_3As{\rightarrow}AuI]$	„	7·17	19·7	8·00	75	2·94	4	$P\ 2_1$
$[Me_3As{\rightarrow}AuI]$	Rhombic	12·0	11·7	11·7	—	3·85	8	*P bcn*
$[Me_3As{\rightarrow}AuSCN]$	Tetragonal	17·3	17·3	11·9	—	2·79	16	*I* 4*cd*

The authors are greatly indebted to Professor Sir William Pope, F.R.S., for a supply of gold, and to the Department of Scientific and Industrial Research for grants.

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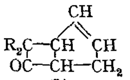
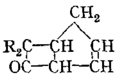
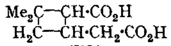
387. *The Constitution of the Condensation Product of Diphenylketen and* cyclo*Pentadiene.*

By J. R. Lewis, G. R. Ramage, J. L. Simonsen, and (in part) W. G. Wainwright.

The condensation of diphenylketen with *cyclo*pentadiene yields by 1 : 2-addition 6-*keto*-7 : 7-*diphenyl*bicyclo[3, 2, 0]*hept-2-ene.* This gives on oxidation with permonophthalic acid an *epoxide*, convertible by acetic–sulphuric acid into the *diacetate* of 2 : 3-*dihydroxy*-6-*keto*-7 : 7-*diphenyl*bicyclo[3, 2, 0]*heptane*, from which by the action of alkali two stereoisomeric 3 : 4-*dihydroxy*-2-*benzhydryl*cyclo*pentane*-1-*carboxylic acids* can be prepared. Oxidation of these with lead tetra-acetate, followed by potassium permanganate, gives two stereoisomeric 4 : 4-*diphenylbutane*-1 : 2 : 3-*tricarboxylic acids*, which have been prepared synthetically by the hydrolysis of the condensation product of bromodiphenylmethane and methyl sodiopropane-ααβγ-tetracarboxylate. It is suggested that the analogous condensation product from dimethylketen and *cyclo*pentadiene might provide a suitable starting material for the synthesis of caryophyllenic acid.

In the course of his well-known investigations on the reactions of the ketens (summarised in " Die Ketene," 1912), Staudinger (*Ber.*, 1906, **39**, 968; *Annalen*, 1907, **356**, 51) prepared by the condensation of dimethylketen and *cyclo*pentadiene a dicyclic unsaturated ketone, $C_9H_{12}O$, for which he suggested the alternative formulæ (I; R = Me) and (II; R = Me). It occurred to us that, if (I) correctly represented the ketone, it might prove a suitable starting point for the synthesis of caryophyllenic acid (III).

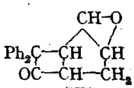
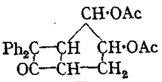
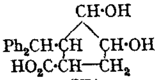
  

(I.) (II.) (III.)

As preliminary experiments on the degradation of this somewhat inaccessible ketone gave products which could not be characterised, we decided to investigate in the first instance the related ketone (I; R = Ph) or (II; R = Ph), which is highly crystalline and can be prepared with comparative ease from diphenylketen.

The experiments now to be described have shown the ketone to be (I; R = Ph), a result which was not anticipated, since the somewhat analogous condensations of *cyclo*pentadiene with ethyl azodicarboxylate (Diels, Blom, and Koll, *Annalen*, 1925, **443**, 242) and with maleic anhydride (Diels and Alder, *ibid.*, 1928, **460**, 98) have given 1 : 4-adducts.

By oxidation of the ketone with permonophthalic acid (Böhme, *Ber.*, 1937, **70**, 379) the *epoxide* (IV), m. p. 121—122°, was obtained in excellent yield and this on treatment with acetic–sulphuric acid formed the *diacetate* (V), m. p. 122—124°, from which the *glycol*, m. p. 178—180°, was prepared by hydrolysis with alcoholic sulphuric acid.

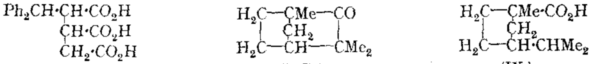
  

(IV.) (V.) (VI.)

Whilst the glycol and its diacetate appear to be stable in acid solution, on treatment with alkali fission of the *cyclo*butane ring occurs with remarkable facility with the formation, depending upon the conditions used, of two stereoisomeric dihydroxy-acids or their esters. By the action of sodium methoxide on the glycol, or of cold methyl-alcoholic potassium hydroxide solution on the diacetate, *methyl* α-3 : 4-*dihydroxy*-2-*benzhydryl*cyclo*pentane*-1-*carboxylate*, m. p. 159—160°, is obtained, yielding on alkaline hydrolysis in the cold the α-*acid*, m. p. 170—171°. If, however, the diacetate, the glycol or the α-methyl ester is digested with an excess of methyl-alcoholic potassium hydroxide solution, an isomeric acid, β-3 : 4-*dihydroxy*-2-*benzhydryl*cyclo*pentane*-1-*carboxylic acid*, m. p. 177—180° (*methyl*

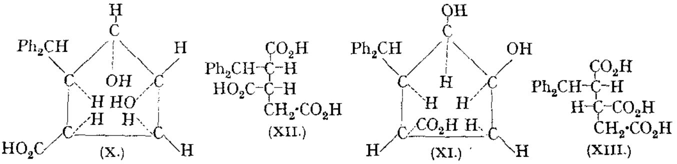
ester, m. p. 126—128°), is obtained. The ease of esterification of the acids and of hydrolysis of their esters suggests that the structure (VI) represents the two isomeric acids and this was proved by their oxidation with lead tetra-acetate, followed by potassium permanganate, to two isomeric α- and β-4 : 4-*diphenylbutane*-1 : 2 : 3-*tricarboxylic acids* (VII), m. p. 185—187° and 208—209° respectively. These acids were prepared synthetically by the hydrolysis of the condensation product of bromodiphenylmethane and methyl sodiopropane-ααβγ-tetracarboxylate, one of the carboxyl groups being eliminated.

The facility with which ring fission occurs in the dihydroxy-ketone is somewhat remarkable, but it finds an approximate parallel in the fission of fenchone (VIII) with potassium hydroxide (Wallach and Wienhaus, *Annalen*, 1909, **369**, 72) or sodamide (Semmler, *Ber.*, 1906, **39**, 2578) to fencholic acid (IX) or its amide.

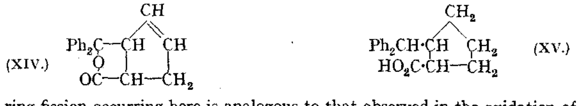


(VII.) (VIII.) (IX.)

Although it has not proved possible to determine the configurations of the two isomeric hydroxy-acids and the related tricarboxylic acids, certain points of interest have emerged. The fact that neither of the hydroxy-acids lactonises necessitates both the hydroxy-groups in the two acids having the *trans*-configuration with respect to the carboxyl group; the hydroxy-groups must therefore be *cis* to one another. This configuration for the hydroxy-groups is supported by the equally facile oxidation of the methyl esters of the α- and the β-dihydroxy-acid with lead tetra-acetate (Criegee, *Ber.*, 1932, **65**, 1771) and, although as a general rule the hydration of an epoxide gives exclusively the *trans*-glycol, it has been observed by Böeseken (*Rec. trav. chim.*, 1928, **47**, 683) that the *cis*-form may predominate in certain cases if the hydration is carried out in acid solution. It follows, therefore, that the most probable representations of the two hydroxy-acids are (X) and (XI), which would on oxidation give the isomeric tricarboxylic acids (XII) and (XIII). It has not, however, proved possible to assign a definite configuration to the acids.



A further example of the facility with which ring fission occurs in the adduct was provided by its oxidation with hydrogen peroxide to an unsaturated *lactone*, $C_{19}H_{16}O_2$, m. p. 116—117°, probably (XIV), which gives on catalytic hydrogenation an acid, $C_{19}H_{20}O_2$, m. p. 125—127°, probably 2-*benzhydryl*cyclo*pentane*-1-*carboxylic acid* (XV).



The ring fission occurring here is analogous to that observed in the oxidation of cyclic ketones with Caro's reagent (compare Robinson and Smith, this vol., p. 371).

Experimental.

6-*Keto*-2 : 3-*epoxy*-7 : 7-*diphenyl*bicyclo[3, 2, 0]*heptane*.—Diphenylketen (from diphenylchloroacetyl chloride, 28 g.) and *cyclo*pentadiene (10 g.) in ligroin (b. p. 40—60°) were kept for 2 days in a carbon dioxide atmosphere. The solvent was removed, and the solid residue crystallised

from methyl alcohol (yield 23 g.; m. p. 86—88°). The condensation product (5 g.) in ether was mixed with an ethereal solution of permonophthalic acid and kept at room temperature for 12—15 days, titration of 2 c.c. portions with N/20-sodium thiosulphate, compared with blank per-acid solution, indicating the completion of the oxidation. The ethereal solution, washed with potassium iodide solution, followed by sodium hydroxide solution, was dried, and the ether removed, leaving the *oxide* (5 g.), which crystallised from *cyclo*hexane and then from methyl alcohol in fine needles, m. p. 121—122° (Found: C, 82·8; H, 5·8. $C_{19}H_{16}O_2$ requires C, 82·6; H, 5·8%).

2 : 3-*Dihydroxy*-6-*keto*-7 : 7-*diphenyl*bicyclo[3, 2, 0]*heptane*.—The oxide (6·4 g.), dissolved in acetic acid (120 c.c.) containing concentrated sulphuric acid (0·5 c.c.), was kept overnight and then poured on ice. The separated solid was dissolved in ether, and the ethereal extract washed with sodium carbonate solution and dried over potassium carbonate. Removal of the solvent left a gum (7·8 g.), which was dissolved in hot methyl alcohol; on cooling, the *diacetate* crystallised in large prismatic needles, m. p. 122°, raised to 122—124° by two further crystallisations from the same solvent [Found: C, 72·6; H, 5·6; OAc, 22·3. $C_{19}H_{16}O(OAc)_2$ requires C, 73·0; H, 5·8; OAc, 22·8%]. The diacetate (0·2 g.), mixed with ethyl alcohol (5 c.c.) and sulphuric acid (0·5 c.c.), was heated on the water-bath for 3 hours. Addition of water to the cooled solution precipitated the *glycol*, which was sparingly soluble in ether and benzene, but crystallised from dilute methyl alcohol or ethyl acetate in balls of needles, m. p. 178—180° (Found: C, 77·8; H, 6·3. $C_{19}H_{18}O_3$ requires C, 77·5; H, 6·1%). The glycol can also be prepared by allowing the diacetate to stand overnight with very dilute methyl-alcoholic potassium hydroxide solution.

α-3 : 4-*Dihydroxy*-2-*benzhydryl*cyclo*pentane*-1-*carboxylic Acid*.—*Methyl ester*. (a) To a well-cooled solution of the diacetate (1 g.) in methyl alcohol (8 c.c.), a cold methyl-alcoholic potassium hydroxide solution (KOH, 0·4 g.; MeOH, 2 c.c.) was added. After keeping overnight, the addition of water precipitated the *α-methyl* ester (0·7 g.), which crystallised from benzene in fine needles, m. p. 159—160° [Found: C, 73·5; H, 6·3; OMe, 9·2. $C_{19}H_{19}O_3(OMe)$ requires C, 73·6; H, 6·7; OMe, 9·5%], sparingly soluble in ether.

(b) To a solution of the glycol (0·5 g.) in methyl alcohol (2 c.c.), sodium methoxide (Na, 0·05 g.) was added. The solution was boiled for 1 minute, kept for an hour, water added, and the separated solid (0·3 g.) collected and crystallised from benzene; m. p. 159—160°, both alone and in admixture with the above ester.

The methyl ester (0·2 g.), when digested with dilute sulphuric acid (conc. acid, 1 c.c.; water, 10 c.c.) for 3 hours, was converted into a gum. This was dissolved in ether, and the ethereal extract washed with sodium carbonate solution, dried, and evaporated. The residue (0·05 g.) crystallised when triturated with benzene and had m. p. 150—170°; it was not further examined. Acidification of the carbonate solution gave the *α-dihydroxy-acid*, which crystallised from ethyl acetate in hard prismatic needles, m. p. 170—171° (Found: C, 72·8; H, 6·5; *M*, 315. $C_{19}H_{20}O_4$ requires C, 73·1; H, 6·4%; *M*, 312). The *ethyl* ester, prepared by treatment of the glycol with sodium ethoxide or by digestion of the methyl ester with ethyl alcohol and sulphuric acid, crystallised from *cyclo*hexane in soft prismatic needles, m. p. 140—141° (Found: C, 74·2; H, 7·2. $C_{21}H_{24}O_4$ requires C, 74·1; H, 7·1%). The *dibenzoate* of the ethyl ester, prepared in pyridine solution, crystallised from ethyl alcohol in soft needles, m. p. 138—139° (Found: C, 77·0; H, 5·6. $C_{35}H_{32}O_6$ requires C, 76·6; H, 5·8%). The p-*bromophenacyl* ester crystallised from dilute acetone in fine needles, m. p. 128—129° (Found: C, 63·7; H, 5·1. $C_{27}H_{25}O_5Br$ requires C, 63·6; H, 4·9%).

β-3 : 4-*Dihydroxy*-2-*benzhydryl*cyclo*pentane*-1-*carboxylic Acid*.—The α-methyl ester (3 g.) was digested with methyl-alcoholic potassium hydroxide solution for 1 hour on the water-bath. After removal of the alcohol, water was added, the solution washed with ether and acidified, and the acid extracted with ether. Removal of the solvent left the *β-dihydroxy-acid* (2·8 g.), m. p. about 155°, raised to 177—180° after several recrystallisations from benzene–acetone (Found: C, 73·0; H, 6·4. $C_{19}H_{20}O_4$ requires C, 73·1; H, 6·4%). The m. p. was somewhat dependent on the rate of heating and the mixed m. p. with the α-dihydroxy-acid was 154° with previous softening. The β-dihydroxy-acid was very sparingly soluble in benzene, toluene and chloroform, somewhat more readily in ether and ethyl acetate, very readily in alcohol and acetone. The acid was obtained also by digestion of the diacetate with methyl-alcoholic potassium hydroxide solution (6 mols.) or by the hydrolysis of the ethyl ester of the α-dihydroxy-acid, but always as a mixture consisting mainly of the β-acid. The *methyl* ester crystallised from *cyclo*hexane in fine needles, m. p. 126—128° (Found: C, 73·6; H, 6·8. $C_{20}H_{22}O_4$ requires C, 73·6; H, 6·7%). The p-*bromophenacyl* ester crystallised from dilute acetone in fine needles, m. p. 154—155° (Found: C, 63·3; H, 4·7. $C_{27}H_{25}O_5Br$ requires C, 63·6; H, 4·9%).

*Oxidation of Methyl α-3 : 4-Dihydroxy-2-benzhydryl*cyclo*pentane-1-carboxylate. Formation of α-4 : 4-Diphenylbutane-1 : 2 : 3-tricarboxylic Acid.*—A standard acetic acid solution of lead tetra-acetate (107 c.c., 1·39N/10) was added to the α-methyl ester (2·2 g.) dissolved in acetic acid (20 c.c., distilled over chromic acid). Titration of 2 c.c. portions showed that the reaction was practically complete in 2—4 minutes. After standing for 1 hour, the acetic acid solution was poured into water and extracted with ether, the extract being washed with sodium carbonate solution and dried. Removal of the solvent left an oil (2 g.), which gave amorphous derivatives with carbonyl reagents. It was dissolved in dry acetone (30 c.c., distilled from potassium permanganate), and finely powdered potassium permanganate (1·4 g.) added slowly. The precipitate was collected and washed with acetone, and sulphur dioxide passed into a suspension of it until the manganese dioxide was in solution. The acid (1·8 g.), isolated by ether extraction, was dissolved in sodium hydroxide solution (20 c.c., 8%) and warmed on the water-bath for 15 minutes. The acidified solution was extracted with ether, removal of the solvent giving the *α-tricarboxylic acid*, which crystallised from formic acid in small prismatic needles, decomp. 187—188° (Found: C, 66·4; H, 5·2. $C_{19}H_{18}O_6$ requires C, 66·7; H, 5·2%). The acid was very readily soluble in alcohol, acetone and hot water, sparingly so in benzene. On heating above its m. p. it gave a gum, probably the acid anhydride. The barium salt was very sparingly soluble, and the calcium salt was sparingly soluble in hot water, readily in cold. The *methyl* ester, prepared by means of diazomethane, crystallised from methyl alcohol in prisms, m. p. 117—119° (Found: C, 68·6; H, 6·1. $C_{22}H_{24}O_6$ requires C, 68·8; H, 6·2%).

*Oxidation of Methyl β-3 : 4-Dihydroxy-2-benzhydryl*cyclo*pentane-1-carboxylate. Formation of β-4 : 4-Diphenylbutane-1 : 2 : 3-tricarboxylic Acid.*—The pure β-methyl ester (0·67 g.) was oxidised with lead tetra-acetate (30 c.c., 1·67N/10), and the neutral product (0·6 g.) further oxidised with potassium permanganate as described above, giving an acid converted by diazomethane into the methyl ester, m. p. 121—122·5°, described below.

A similar oxidation of the crude β-methyl ester (3·7 g.) gave the tricarboxylic acid as a yellow oil, which crystallised after trituration with formic acid and then had m. p. 173—203°. The acid (0·5 g.) was heated with hydrochloric acid (concentrated acid, 5 c.c.; water, 5 c.c.) at 200° for 24 hours; the product was dissolved in ether and, after removal of the solvent, crystallised from formic acid. The solid which separated, m. p. 180—192°, was dissolved in hot water, and the solution filtered from a little tar and kept in the ice-box overnight. The *β-tricarboxylic acid*, which was deposited, decomp. 203—205°, crystallised twice from formic acid (charcoal), separated in fine needles, decomp. 208—209° (Found: C, 66·7; H, 5·7. $C_{19}H_{18}O_6$ requires C, 66·7; H, 5·2%). The *β-methyl* ester, prepared by means of diazomethane, crystallised from methyl alcohol in rosettes of prisms, m. p. 121—122·5°, depressed to 110° on admixture with the methyl ester of the α-tricarboxylic acid (Found: C, 68·4; H, 6·1. $C_{22}H_{24}O_6$ requires C, 68·8; H, 6·2%).

Condensation of Methyl Propane-ααβγ-tetracarboxylate and *Bromodiphenylmethane.*—To a solution of methyl sodiopropane-ααβγ-tetracarboxylate (from the ester, 10 g.) in benzene (50 c.c.), bromodiphenylmethane (9 g.) was added, and the mixture boiled for 24 hours. After addition of water to the cooled solution, the benzene layer was separated and dried, and the solvent removed. Distillation of the residual oil at 5 mm. gave, after a low-boiling fraction, the condensation product (8 g.), b. p. 258°, as a very viscid oil which set to a hard glass. This was dissolved in methyl alcohol and hydrolysed with methyl-alcoholic potassium hydroxide solution (KOH 8 g.). After removal of the alcohol, the solution was acidified, the gummy acid collected in ether, the solvent removed, and the residue digested with hydrochloric acid for 4 hours. The acid was again recovered by ether extraction and, after removal of the solvent, dissolved in aqueous ammonia, and the sparingly soluble barium salt precipitated in three fractions. The acid (1·9 g.) from the most sparingly soluble fraction was repeatedly crystallised from formic acid (charcoal), α-4 : 4-diphenylbutane-1 : 2 : 3-tricarboxylic acid being ultimately obtained in prismatic needles, decomp. 185°, both alone and in admixture with the α-tricarboxylic acid described above (Found: C, 66·4; H, 5·4%). The acids (1 g. and 3 g.) separated from the remaining fractions of the barium salt were somewhat gummy and after crystallisation from formic acid each had m. p. 150—170°. They were combined and heated at 200° for 24 hours with hydrochloric acid (concentrated acid, 10 c.c.; water, 10 c.c.). The acid, isolated by means of ether, was dissolved in formic acid and, on cooling, the solution deposited a fraction, m. p. 170—185°, consisting of the nearly pure α-tricarboxylic acid; the filtrate (*A*) was reserved. The acid was dissolved in hot water and filtered from a little tar and the solid which separated on cooling was crystallised twice from formic acid, the α-tricarboxylic acid, decomp. 185°, being obtained. The identity was confirmed by the preparation of the methyl ester, m. p. 117—118°

both alone and in admixture with the methyl ester of the α-tricarboxylic acid described on p. 1840.

The formic acid filtrate (*A*) was evaporated on the water-bath until free from the solvent, and the gummy residue digested with hot water, which left undissolved a red tar. The aqueous solution, kept overnight in the ice-box, deposited a solid which after three crystallisations from formic acid (charcoal) gave the pure β-4 : 4-diphenylbutane-1 : 2 : 3-tricarboxylic acid, decomp. 208—209° both alone and in admixture with the β-tricarboxylic acid described on p. 1840 (Found : C, 66·4; H, 5·5%). The methyl ester, prepared by digestion of the acid with methyl alcohol and sulphuric acid for 8 hours, crystallised from methyl alcohol in rosettes of prisms, m. p. 124—125°, which in admixture with the methyl ester of the β-tricarboxylic acid, m. p. 121—122·5° (p. 1840), had m. p. 122—124° (Found : C, 68·6; H, 6·0%).

*Oxidation of 6-Keto-7 : 7-diphenyl*bicyclo[3, 2, 0]*hept-2-ene with Hydrogen Peroxide*.—To a solution of the dicyclic ketone (5 g.) in methyl alcohol (150 c.c.) cooled to − 10°, a mixture of methyl-alcoholic potassium hydroxide solution (KOH, 1 g.) and hydrogen peroxide (8·5 c.c.; 15%) was slowly added; the whole was kept for 1 hour in the freezing mixture and for 2 hours at room temperature. Water (600 c.c.) was then added, and the *lactone* taken up in ether. The residue (5 g.) after removal of the solvent crystallised from *cyclo*hexane or methyl alcohol in prisms, m. p. 116—117° (Found : C, 82·5; H, 6·2. $C_{19}H_{16}O_2$ requires C, 82·5; H, 5·8%). The lactone was soluble in hot alkali solution and precipitated on acidification.

*2-Benzhydryl*cyclo*pentane-1-carboxylic Acid* (XV?).—The lactone (1 g.) was reduced in alcoholic solution with hydrogen and a palladium-norit catalyst, the hydrogen absorption corresponding to two molecules. The viscid oil obtained on evaporation of the alcohol was dissolved in sodium carbonate solution; this was washed with ether and acidified, and the acid extracted with ether. Removal of the solvent gave the cyclo*pentane acid* (0·8 g.), which crystallised from ligroin (b. p. 40—60°) in large cubes with bevelled edges, m. p. 125—127°, sintering at 117° (Found : C, 81·3; H, 7·1. $C_{19}H_{20}O_2$ requires C, 81·4; H, 7·1%).

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The University College of North Wales, Bangor. [*Received, September 28th*, 1937.]

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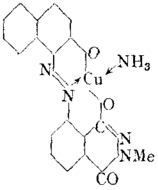
388. *Chemiluminescent Organic Compounds. Part V. The Methyl Derivatives of 5-Nitro- and 5-Amino-phthalaz-1 : 4-dione. Structural Features in Relation to Chemiluminescence.*

By H. D. K. Drew and R. F. Garwood.

5-Aminophthalaz-1 : 4-dione is probably the most powerfully chemiluminescent member of the *cyclo*hydrazide series. The object of the work was to substitute methyl for hydrogen in all possible positions of the hydrazide ring of this substance, to determine the structures of the methyl derivatives, and then to trace the effect of the structural changes on the luminescence property. In this way we hoped to get a clue to the nature of the change concerned in the luminescence, even although the luminescing molecules represent only a small fraction of 1% of the *cyclo*hydrazide molecules present. Seven out of the eight possible methyl derivatives have now been prepared and examined. The crucial step in settling the orientation of the methyl groups was taken by preparing the copper lakes of the azo-β-naphthol derivatives of the mono-*N*-methyl compounds and determining their structures. Further methylation then gave the structures of the dimethylated derivatives. The chief conclusion from the work is that chemiluminescence is dependent on the ion derived from the dilactim form of the *cyclo*hydrazide. This in all probability forms a peroxide, directly responsible for the reaction which initiates the radiation. The peroxide has not yet been characterised.

The orientation of the methyl group in the α- and the β-form of 5-amino-*N*-methylphthalaz-1 : 4-dione, and therefore also in the 5-nitro-compounds from which the amino-compounds were obtained by reduction (Drew, Hatt, and Hobart, this vol., p. 33), has now been

ascertained by determination of the structures of the cupric derivatives of the *azo*-compounds formed by coupling the respective diazotised amines with β-naphthol. The azo-compound of the α-form, when treated with aqueous cupric chloride and ammonia, gave the *amminocupric* derivative (I), which did not combine with more copper when boiled with aqueous cupric chloride, showing that a hydroxyl group was present in the 4-position of the hydrazide ring; whereas the azo-compound of the β-form gave, under the same conditions, the *ammonium* salt of the *hydroxycupric* derivative (II), which with aqueous cupric chloride became the *cupric* salt of the hydroxycupric complex [*i.e.*, $Cu_{\frac{1}{2}}$ *for* NH_4 *in (II)*], *showing that a carbonyl group was present in the 4-position.* These copper lakes appear to be of novel type. Analysis of the corresponding derivatives with pyridine in place of ammonia confirmed the composition of the complexes, although, owing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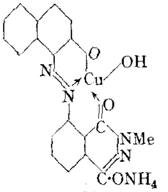
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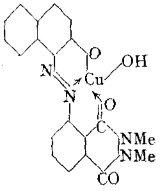
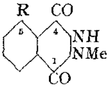

(III.)

to a tendency towards loss of pyridine as vapour, the pyridine compounds were not obtained pure. For comparison, the *cupric* derivative (III) of the azo-compound from 5-amino-2 : 3-dimethylphthalaz-1 : 4-dione was prepared in presence of pyridine; it proved to be similar in type to (II), but, as was to be expected, was incapable of adding pyridine. α-5-Amino-*N*-methylphthalaz-1 : 4-dione is therefore *5-amino-2-methylphthalaz-1 : 4-dione* (IV; R = NH_2) and the β-compound is the *3-methyl* isomeride.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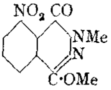
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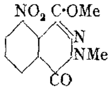
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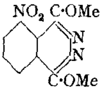
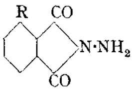

(VII.)

There are four possible dimethyl derivatives of 5-nitrophthalaz-1 : 4-dione with the methyl groups substituted in the hydrazide ring, one of which, the 2 : 3-dimethyl compound is already known (*loc. cit.*). The remainder have now been obtained. With methyl sulphate, 5-nitrophthalaz-1 : 4-dione became methylated initially in the 3-position, the *product being a mixture of* 5-nitro-3-methylphthalaz-1 : 4-dione, which *is evidently the* hitherto unidentified substance (m. p. 264°) obtained by Mihailescu and Protopopescu (*Bul. Soc. Chim. România*, 1930, **12**, 95), together with its *O*-methyl derivative, *5-nitro-1-methoxy-3-methylphthalaz-4-one* (V). The last substance was obtained also in two other ways: (i) *methylation of the silver salt of* 5-nitrophthalaz-1 : 4-dione *gave an O-methyl* derivative, which on further methylation gave (V); the *O*-methyl derivative was therefore *5-nitro-1-methoxyphthalaz-4-one*; and (ii) methylation of the silver salt of 5-nitro-3-methylphthalaz-1 : 4-dione. Methylation of the silver salt of 5-nitro-1-methoxyphthalaz-4-one gave *5-nitro-1 : 4-dimethoxyphthalazine* (VII). Finally, methylation of the silver salt of 5-nitro-2-methylphthalaz-1 : 4-dione (*IV; R* = NO_2) gave 5-nitro-4-methoxy-2-methylphthalaz-1-one (VI). The *amino*-compounds corresponding with (V), (VI), and (VII) also were prepared. Of the four possible monomethyl derivatives of 5-nitrophthalaz-1 : 4-dione with the methyl group in the hydrazide ring, only 5-nitro-4-methoxyphthalaz-1-one now remains unknown; the same holds for the corresponding 5-amino-compounds.

The action of methylhydrazine upon the following substances gave rise in each case to a mixture of the α- and the β-form of the corresponding *cyclo*hydrazides: 3-nitro-2-

carbethoxybenzoic acid, 3-nitro-2-carbethoxybenzoyl chloride, 6-nitro-2-carbethoxybenzoic acid, 3-acetamidophthalic anhydride, and 3-aminophthalimide. The reactions with the last two afforded an independent means of synthesising the α- and the β-forms of 5-amino- and of 5-acetamido-methylphthalaz-1 : 4-dione, previously obtained only by reduction of the nitro-compounds. The physical properties of the amino- and the nitro-methylphthalaz-1 : 4-diones prepared during the present work confirm the data previously given (this vol., p. 33, *footnote*).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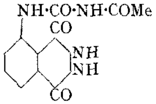
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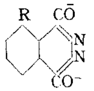
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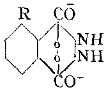
(XI.)

3-*Nitro*-N-*aminophthalimide* (VIII; R = NO_2) and 3-*acetamido*-N-*aminophthalimide* were prepared; they are readily transformed into the corresponding *cyclo*-hydrazides. 5-*Acetcarbamidophthalaz*-1 : 4-*dione* (IX) was strongly chemiluminescent on oxidation in presence of alkali.

It has already been shown (*loc. cit.*) that the substitution of methyl for both of the enolisable hydrogen atoms of the highly luminescent amino-*cyclo*hydrazides caused complete loss of chemiluminescence, and the substitution for only one of them caused such a profound diminution in this property as to suggest that the residual activity was due to traces of unmethylated product. We have now shown that this is so in the case of 5-amino-2-methylphthalaz-1 : 4-dione, prepared by the action of methylhydrazine on 3-aminophthalimide: eight crystallisations of its acetyl derivative from acetic anhydride gave a specimen (m. p. 190°), which on hydrolysis of the acetyl group gave the amine (m. p. 309°); the latter showed no trace of luminescence on oxidation with hydrogen peroxide in alkaline solution in presence of hæmoglobin, whereas the uncrystallised substance showed the usual feeble chemiluminescence. It may therefore be concluded that *the presence of both of the imino-hydrogen atoms of the* cyclo*hydrazides is essential for chemiluminescence.*

Since the luminescence appears only in alkaline solution and since more than one equivalent of alkali is necessary for its highest development (compare Drew and Pearman, this vol., p. 588), it is strongly indicated that the luminescent agent is the di-enolised (lactim) form of the molecule. This is supported by the fact that neither of the amino-*cyclo*hydrazides corresponding with (V) and (VI) was chemiluminescent. The matter can be carried a step further, since we observed that 5-amino-1 : 4-dimethoxyphthalazine (as VII), which has the dilactim form, is also non-luminescent, leading to the conclusion that the ion (X) is the essential structure for luminescence.

We have obtained some evidence, though at present inconclusive, that a peroxide, which might have the form (XI), is produced by the addition of hydrogen peroxide to (X). As a working hypothesis, it seems possible that the chemiluminescence follows the oxidation of the imino-hydrogen atoms of the peroxide and the consequent elimination of an oxygen molecule with regeneration of the original *cyclo*hydrazide ion. Attempts to characterise the peroxide are in progress.

Experimental.

5-*Acetcarbamidophthalaz*-1 : 4-*dione* (IX).—3-Acetcarbamidophthalic anhydride (Scott and Cohen, J., 1921, **119**, 667) (2 g.) was heated under reflux (1 hour) in glacial acetic (20 c.c.) containing hydrazine hydrate (0·4 c.c.). The cyclo*hydrazide* separated on cooling; it was purified by precipitation from a solution in 5% aqueous sodium hydroxide with acetic acid and was obtained as a yellowish powder, m.p. 320° (decomp.), which was strongly chemiluminescent (greenish-yellow) (Found: C, 50·3; H, 4·15. $C_{11}H_{10}O_4N_4$ requires C, 50·4; H, 3·8%).

3-*Acetamido*-N-*aminophthalimide* (VIII; R = NH·COMe).—3-Acetamidophthalimide (2 g.) was added to alcohol (30 c.c.), and hydrazine hydrate (0·6 c.c.) run in. The mixture was shaken for 5 minutes, boiled for 5 minutes, and poured into water (300 c.c.); the required *substance* then crystallised. From its yellow solutions in alcohol or water it formed colourless needles

(Found: C, 54·5; H, 4·3. $C_{10}H_9O_3N_3$ requires C, 54·8; H, 4·1%), m.p. 163° (with *transformation into the cyclo*hydrazide). It was soluble in organic solvents and strong acids but not in alkali, and it reduced warm Fehling's solution; it was not chemiluminescent, but became so when boiled with alkali, owing to transformation into the *cyclo*hydrazide. The *benzylidene* derivative was obtained in long white needles, m. p. 214°, from alcohol (Found: C, 66·65; H, 4·85. $C_{17}H_{13}O_3N_3$ requires C, 66·45; H, 4·25%). The *p*-anisylidene derivative formed colourless fibrous needles, m. p. 186°.

3-*Amino*-N-*anilinophthalimide*.—This was prepared by heating under reflux (3 hours) 3-aminophthalimide (1 g.) with phenylhydrazine (0·7 c.c.) in water (50 c.c.); yellow crystals separated and were washed with aqueous ammonia and recrystallised from dilute alcohol (yield, 1·4 g.). The substance had m. p. 222° (Found: C, 66·2; H, 4·6. Calc. for $C_{14}H_{11}O_2N_3$: C, 66·45; H, 4·35%), was insoluble in alkalis but soluble in acids, and reduced Fehling's solution; on acetylation it gave 3-acetamido-*N*-anilinophthalimide, m. p. 179°, identical with that obtained from 3-acetamidophthalic anhydride and phenylhydrazine (this vol., p. 30). Since this work was done, Gleu and Pfanstiehl have described the substance (*J. pr. Chem.*, 1936, **146**, 137).

Condensation of Methylhydrazine and 3-Aminophthalimide.—When a mixture of methylhydrazine sulphate (3·5 g.; 2 mols.) in water (20 c.c.), 5% aqueous sodium hydroxide (40 c.c.), and 3-aminophthalimide (2 g.) was heated under reflux (2 hours), ammonia was evolved. The clear solution gave on acidification with acetic acid crystals of a mixture (2·2 g.; m. p. 260—270°) of α- and β-5-amino-*N*-methylphthalaz-1 : 4-diones; two crystallisations from glacial acetic acid gave the pure α-form, m. p. 308° (compare this vol., p. 35).

Condensation of Methylhydrazine and 2-Carbethoxy-3 or -6-nitrobenzoic Acid.—In each case a mixture of the benzoic acid derivative (1 g.), methylhydrazine sulphate (0·6 g.; 1 mol.), and hydrated sodium acetate (1·1 g.) was dissolved in alcohol, evaporated to dryness, and heated gradually to 150°. After cooling, the product was dissolved in 5% aqueous sodium hydroxide, and dilute acetic acid added: the crystals were in each case a mixture of the α- and the β-form of 5-nitro-*N*-methylphthalaz-1 : 4-dione, which were separated by the methods previously described (this vol., pp. 35, 36). A similar result was obtained on condensing methylhydrazine with 3-nitro-2-carbethoxylbenzoyl chloride in acetic acid.

Methylation of 5-Nitrophthalaz-1 : 4-dione.—Methylation of 1 g. with methyl sulphate (0·7 c.c.) at 120—130° (8 hours) gave a mixture of substances, from which the following were isolated: (*a*) β-5-nitro-*N*-methylphthalaz-1 : 4-dione, m. p. 275°, which was separated through its solubility in sodium hydroxide; (*b*) a dimethyl derivative (see below), colourless needles, m. p. 139°, from water, which was later shown to be the *O*-methyl ether of β-5-nitro-*N*-methylphthalaz-1 : 4-dione.

5-*Nitro*-1-*methoxy*-3-*methylphthalaz*-4-*one* (V).—The silver salt (1 g.) of 5-nitro-3-methylphthalaz-1 : 4-dione prepared from the ammonium salt and aqueous silver nitrate (yellow plates, insoluble in water) was refluxed with methyl iodide (1 c.c.) in methyl alcohol (20 c.c.), the silver iodide removed, and the residue from the filtrate crystallised from water: the colourless needles, m. p. 139°, were identical with those mentioned at (*b*) above (Found: C, 51·2; H, 4·15. $C_{10}H_9O_4N_3$ requires C, 51·1; H, 3·8%). Zellner and Dougherty have since described this substance (*J. Amer. Chem. Soc.*, 1936, **58**, 1811), but have not determined the structure.

5-*Nitro*-4-*methoxy*-2-*methylphthalaz*-1-*one* (VI).—The *silver* salt of α-5-nitro-*N*-methylphthalaz-1 : 4-dione [yellow; slightly soluble in hot water (Found: Ag, 32·9. $C_9H_6O_4N_3Ag$ requires Ag, 32·9%)] gave, with methyl-alcoholic methyl iodide as before, the required *substance*, which formed plates, m. p. 199—200°, from dilute alcohol (Found: C, 51·1; H, 4·15. $C_{10}H_9O_4N_3$ requires C, 51·1; H, 3·85%). Zellner and Dougherty (*loc. cit.*) give m. p. 207°.

5-*Amino*-4-*methoxy*-2-*methylphthalaz*-1-*one* (as VI), prepared by reduction of the nitro-compound with tin and hydrochloric acid, formed white needles, m. p. 136°, from water (Found: C, 58·5; H, 5·8. $C_{10}H_{11}O_2N_3$ requires C, 58·5; H, 5·35%). Its 5-N-*acetyl* derivative formed colourless needles, m. p. 187°, from alcohol (Found: C, 58·6; H, 5·5. $C_{12}H_{13}O_3N_3$ requires C, 58·4; H, 5·25%).

5-*Amino*-1-*methoxy*-3-*methylphthalaz*-4-*one* (as V), similarly prepared, crystallised in white needles, m. p. 222°, from water (Found: C, 58·3; H, 5·5%). Its 5-N-*acetyl* derivative had m. p. 220° (Found: C, 57·9; H, 5·4%).

2-*Methylphthalaz*-1 : 4-*dione*-5-*azo*-β-*naphthol* was prepared in the usual manner from α-5-amino-*N*-methylphthalaz-1 : 4-dione as a brick-red powder, m. p. 334° (decomp.); on crystallisation from pyridine it gave red needles having the same m. p. (Found: C, 65·7; H, 4·4. $C_{19}H_{14}O_3N_4$ requires C, 65·9; H, 4·05%).

3-Methylphthalaz-1 : 4-dione-5-azo-β-naphthol was similarly obtained from β-5-amino-*N*-methylphthalaz-1 : 4-dione; it separated as a brick-red powder, m. p. 326° (decomp.), from pyridine (Found: C, 65·4; H, 4·3%).

Copper Salts.—(a) *From 2-methylphthalaz-1 : 4-dione-5-azo-β-naphthol.* (i) *Amminocupric salt* (I). A solution of hydrated cupric chloride (0·2 g.) in water (10 c.c.) and concentrated aqueous ammonia (10 c.c.) was shaken with the azo-compound (0·2 g.) for 1 hour; the *copper* salt was filtered off, washed with aqueous ammonia, dried over calcium chloride, and freed from impurities by extraction with chloroform (Soxhlet); the residue consisted of violet crystals with greenish-gold reflex, soluble in alcohol (Found: C, 53·1; H, 4·4; Cu, 15·1. $C_{19}H_{15}O_3N_5Cu$ requires C, 53·6; H, 3·55; Cu, 14·9%). When this salt was boiled with aqueous cupric chloride, it did not absorb more copper, but appeared to lose the molecule of ammonia.

(ii) *Pyridinocupric salt.* The azo-compound (1 mol.), dissolved in hot pyridine, was treated with cupric chloride (1 mol.) in a little water. The deep purple solution was boiled for a few minutes, cooled, filtered, and diluted with water (4 vols.); purple needles with greenish reflex slowly separated and were washed with water and dried over calcium chloride. The *compound* was soluble in organic solvents, forming deep purple solutions, and evolved pyridine when boiled with water or alkali. The same salt was formed when 2 mols. of cupric chloride were used (Found: C, 56·6; H, 4·2; N, 13·6; Cu, 12·7. $C_{24}H_{17}O_3N_5Cu,H_2O$ requires C, 57·1; H, 3·8; N, 13·85; Cu, 12·6%).

(b) *From 3-methylphthalaz-1 : 4-dione-5-azo-β-naphthol.* (i) *Ammonium cupric salt* (II). This was obtained as above as a violet crystalline powder, soluble in organic solvents; it lost ammonia when boiled with alkali (Found: C, 50·9; H, 4·2; Cu, 14·9. $C_{19}H_{17}O_4N_5Cu$ requires C, 51·5; H, 3·85; Cu, 14·4%). When the salt was boiled with aqueous cupric chloride, it was converted into the *dicupric* salt (II, with $Cu_{\frac{1}{2}}$ instead of NH_4) (Found: Cu, 20·1. $C_{38}H_{26}O_8N_8Cu_3,2H_2O$ requires Cu, 20·1%).

(ii) *Pyridinocupric salt.* This was obtained as in the former case, but was gelatinous when first precipitated; dried over calcium chloride, it became a purplish-black powder, insoluble in water but soluble in organic solvents (Found: C, 53·4; H, 4·0; N, 13·4; Cu, 12·1. $C_{24}H_{19}O_4N_5Cu$ requires C, 57·1; H, 3·8; N, 13·85; Cu, 12·6%. $C_{24}H_{19}O_4N_5Cu,H_2O$ requires C, 55·1; H, 4·0; N, 13·4; Cu, 12·2%). The same substance was produced when 2 mols. of cupric chloride or acetate were used.

(c) *From 2 : 3-dimethylphthalaz-1 : 4-dione-5-azo-β-naphthol.* The *cupric* salt (III), prepared in pyridine with cupric chloride and obtained by evaporation, was washed with water and purified by extraction with alcohol; the evaporated alcoholic extract left a purplish-red powder with greenish reflex (Found: C, 55·2; H, 4·4; Cu, 15·2. $C_{20}H_{16}O_4N_4Cu$ requires C, 54·6; H, 3·65; Cu, 14·5%).

5-Nitro-1-methoxyphthalaz-4-one was prepared by heating under reflux (2 hours) the orange-yellow silver salt of 5-nitrophthalaz-1 : 4-dione (10 g.) with methyl iodide (6 c.c.) and methyl alcohol (200 c.c.); the silver iodide was removed, the filtrate evaporated, and the residue fractionated from methyl alcohol. After seven crystallisations, the required *O*-methyl ether was obtained in colourless plates, m. p. 269°, slightly soluble in hot water and soluble in alkali; its solubility in organic solvents was much higher than that of the *N*-methyl ether (Found: C, 48·9; H, 4·0. $C_9H_7O_4N_3$ requires C, 48·9; H, 3·15%). Its *acetyl* derivative formed colourless prisms, m. p. 188—190° (Found: C, 50·0; H, 3·6. $C_{11}H_9O_5N_3$ requires C, 50·2; H, 3·45%). Its sodium salt formed colourless nacreous plates, soluble in water to a yellow solution. Methylation of the *O*-methyl ether in dilute caustic soda solution with methyl sulphate gave 5-nitro-1-methoxy-3-methylphthalaz-4-one (above), m. p. and mixed m. p. 139°: this verifies the structure.

5-Amino-1-methoxyphthalaz-4-one was prepared by reducing the foregoing nitro-compound with tin and hydrochloric acid; the rhomboidal tablets of the stannichloride of the amine were decomposed with calcium carbonate, and the amine obtained in colourless felted needles, m. p. 234° (Found: C, 56·2; H, 5·0. $C_9H_9O_2N_3$ requires C, 56·5; H, 4·7%). It was moderately soluble in boiling water, readily in hot alcohol, and soluble in aqueous caustic soda.

1 : 4-*Dimethoxyphthalazine.*—The silver salt of 1-methoxyphthalaz-4-one was prepared as a greyish-white mass which contained silver oxide but was sufficiently pure to undergo methylation. This was carried out with boiling methyl-alcoholic methyl iodide (2 hours), the *dimethyl* ether being obtained from the filtered solution in colourless hexagonal plates; boiling with 5% aqueous sodium hydroxide removed a little of the monomethyl ether. The substance melted at 121°, but sintered from 100° (Found: N, 15·1. $C_{10}H_{10}O_2N_2$ requires N, 14·75%); evaporation with 40% hydrobromic acid demethylated it completely, giving the *cyclo*hydrazide.

5-*Nitro*-1 : 4-*dimethoxyphthalazine* (VII) was prepared by methylating the crude silver salt (greyish-yellow) of 5-nitro-1-methoxyphthalaz-4-one (above) with methyl iodide in methyl alcohol. It formed colourless needles, m. p. 212—214°, from dilute ethyl alcohol, and was insoluble in alkali and only very sparingly soluble in boiling water (Found: C, 51·3; H, 4·0. $C_{10}H_9O_4N_3$ requires C, 51·1; H, 3·8%). It was not chemiluminescent.

5-*Amino*-1 : 4-*dimethoxyphthalazine* was obtained by reducing the above nitro-ether with tin and hydrochloric acid at 60°; it formed faintly yellow prisms, m. p. 172—174°, from aqueous alcohol (Found: C, 58·5; H, 5·45. $C_{10}H_{11}O_2N_3$ requires C, 58·5; H, 5·35%), and was soluble in acids but not in alkalis.

Action of Methylhydrazine on 3-Acetamidophthalic Anhydride.—Condensation in boiling acetic acid (1 hour) gave a mixture of α- and β-5-acetamido-*N*-methylphthalaz-1 : 4-diones (m. p. 264°). After four crystallisations from glacial acetic acid, the α-form, 5-*acetamido*-2-*methylphthalaz*-1 : 4-*dione*, was obtained pure in white needles, m. p. 291° (Found: C, 57·0; H, 5·1. $C_{11}H_{11}O_3N_3$ requires C, 56·7; H, 4·7%). Hydrolysis of the acetyl group gave the pure α-amino-*cyclo*hydrazide, m. p. and mixed m. p. 308°.

The following preparations were made with the help of Dr. H. H. Hatt and Mr. S. C. Goddard, B.Sc., to whom we are indebted.

3-*Nitro*-N-*aminophthalimide*.—3-Nitrophthalimide (3 g.) in 20 c.c. of cold water was treated with hydrazine hydrate (0·78 g.). From the filtered liquid, some 5-nitrophthalaz-1 : 4-dione separated after 1 day and was removed; after 2 days more, orange needles of the required substance separated (0·5 g.), m. p. 192° (after two crystallisations from alcohol), with re-solidification owing to change into the *cyclo*hydrazide. 3-*Nitro*-N-*aminophthalimide* was slightly soluble in water; on being boiled with water, it tended to change into 5-nitrophthalaz-1 : 4-dione. It formed a benzylidene derivative and reduced ammoniacal silver nitrate, Fehling's solution, and Nessler's reagent (Found: C, 46·3; H, 2·6; N, 20·7. $C_8H_5O_4N_3$ requires C, 46·4; H, 2·4; N, 20·3%). When it was dissolved in hot glacial acetic acid and sodium nitrite added, 3-nitrophthalimide separated on cooling (m. p. and mixed m. p. 215—216°). Further, when it was condensed with phthalic anhydride in glacial acetic acid, 3-nitro-*N*-aminophthalimide gave *N*-3′-nitrophthalimidophthalimide (m. p. and mixed m. p. 246°) (Drew and Hatt, this vol., p. 22). The last two reactions verify the structure.

3 : 3′-*Dinitro*-N-*phthalimidophthalimide* was prepared: (i) by refluxing 3-nitro-*N*-aminophthalimide (0·25 g.) and 3-nitrophthalic anhydride (0·5 g.) in glacial acetic acid (½ hour); addition of water precipitated the required substance, which was crystallised from alcohol; (2) by adding hydrazine hydrate (2 g.) in glacial acetic acid (40 c.c.) slowly to 3-nitrophthalic anhydride (15·6 g.) in the same solvent (40 c.c.) and heating the mixture under reflux (2 hours); crystals (6 g.) of the required substance separated and were freed from admixed *cyclo*hydrazide by keeping for some hours under very dilute aqueous ammonia (400 c.c.). The substance (Found: C, 49·8; H, 1·8; N, 15·3. $C_{16}H_6O_8N_4$ requires C, 50·2; H, 1·6; N, 14·7%) formed pale yellow micro-crystals, m. p. 321°, and was insoluble in water and most organic solvents; it was sparingly soluble in glacial acetic acid. It was hydrolysed by cold sodium hydroxide solution (5%), giving 3-nitrophthalic acid and the *cyclo*hydrazide, together with an unidentified product (yellow needles, m. p. 315°, soluble in water). The action of hydrazine hydrate in acetic acid also gave the *cyclo*hydrazide. Mineral acids gave 3-nitrophthalic acid and other products.

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QUEEN MARY COLLEGE (UNIVERSITY OF LONDON). [*Received, September 23rd*, 1937.]

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389. *The Potential of the Normal and the Decinormal Calomel Electrodes at Temperatures ranging from 12·5° to 91°.*

By H. T. S. BRITTON and GEORGE WELFORD.

The potentials of the normal and the decinormal calomel electrodes have been determined at a series of temperatures. These electrodes have been standardised with respect to the arbitrary hydrogen standard at the various temperatures. For the

purpose, a specially designed thermostat, in which temperatures were controlled by the vapours of boiling liquids, was used.

ALTHOUGH the potentials of the N/10-calomel electrode at temperatures within the range 0—75° are known (Sørensen, *Ergebn. Physiol.*, 1912, **12**, 393), yet those of the N-calomel half-element above 30° have received but little attention. In the present work, these potentials have been determined with respect to that of the normal hydrogen electrode over the range 12·5—91°, and compared with those of the N/10-calomel electrode. To determine the hydrogen half-elements which are assumed arbitrarily at the various temperatures to be of zero potential, advantage has been taken of Noyes's conductivity data (*J. Amer. Chem. Soc.*, 1908, **30**, 335) of hydrochloric acid solutions, and the degrees of ionisation have accordingly been computed on the basis of Arrhenius's theory. Such a scheme has the advantage that the results so obtained for the two types of calomel electrode can be compared directly.

Furthermore, it is not possible to employ the activity concept over the entire temperature range studied, as Harned and Ehlers's activity data (*ibid.*, 1933, **55**, 2179) for hydrochloric acid extend only to 60°. Despite the empirical nature of the Arrhenius theory and the approximations involved in its use, it is probable that any small discrepancies thereby introduced will not seriously interfere with the usefulness of the data now presented.

The *E.M.F.*'s of the following two cells were measured:

(i) $\overset{-}{Pt}|H_2$ (1 atm. — satd. vap. press. of H_2O); 0·08N-HCl | Satd. KCl | N-KCl; Hg_2Cl_2 | $\overset{+}{Hg}$

(ii) $\overset{+}{Hg}$ | Hg_2Cl_2; 0·1N-KCl | 1N-KCl; Hg_2Cl_2 | $\overset{-}{Hg}$

Contrary to the observations of Kolthoff and Tekelenburg (*Proc. K. Akad. Wetensch. Amsterdam*, 1926, **29**, 766; *Rec. trav. chim.*, 1927, **46**, 33), the N-calomel electrode was found to give readily reproducible values at higher temperatures, and therefore to be quite serviceable.

The very small errors involved in the assumption that the saturated water-vapour pressures are equal to those of the dilute hydrochloric acid used are most probably negligible. In the first cell the interposition of a saturated solution of potassium chloride was assumed to eliminate the diffusion potential, and in the second cell such a potential difference was on theoretical grounds considered to be almost non-existent. Col. 2 of Table I gives the *E.M.F.*'s of cell (i) at the temperatures indicated in col. 1. The pressure (*P* in mm. of Hg) of hydrogen supplied to each electrode, col. 3, is equal to that of the atmosphere less the partial pressure of water vapour at each temperature. The potential of the hydrogen electrode at each temperature, col. 6, was calculated by means of the formula

$$E_{H_2} = 0{\cdot}0001984T\,.\log[H^\cdot]/\sqrt{P/760}$$

$[H^\cdot]$ being equal to α_{HCl} (col. 4), computed from Noyes's data, multiplied by 0·08, this being the normality of the hydrochloric acid used.

TABLE I.

Temp.	*E.M.F.*, volt.	*P.*	α_{HCl}.	$[H^\cdot] \times 10^2$.	E_{H_2} (N-H = 0).	$E_{N\text{-}Cal.}$ (N-H = 0).
12·5°	0·351	749	0·934	7·47	− 0·064	+ 0·287
25	0·352	736	0·929	7·43	− 0·067	+ 0·285
34	0·352	720	0·925	7·40	− 0·068	+ 0·284
53	0·349	653	0·917	7·34	− 0·071	+ 0·278
63	0·347	589	0·913	7·30	− 0·072	+ 0·275
75	0·342	471	0·908	7·26	− 0·072	+ 0·270
91	0·325	214	0·901	7·21	− 0·062	+ 0·263

In Table II the potentials of the N/10- and the N-calomel electrode are compared, the extent to which the former is the more positive being given in col. 2. Addition of the values of the latter from Table I gives those of the former (col. 4). These data are in excellent agreement with those extrapolated from Sørensen's data, as shown in col. 5.

Incidentally, this agreement points to the accuracy (within 1 mv.) of the *E.M.F.* values given in Table I.

TABLE II.

Temp.	*E.M.F.*, volt.	$E_{N\text{-Cal.}}$ (N-H=0).	$E_{0\cdot1N\text{-Cal.}}$ (N-H=0).	$E_{0\cdot1N\text{-Cal.}}$ (Sørensen).	Temp.	*E.M.F.*, volt.	$E_{N\text{-Cal.}}$ (N-H=0).	$E_{0\cdot1N\text{-Cal.}}$ (N-H=0).	$E_{0\cdot1N\text{-Cal.}}$ (Sørensen).
25°	0·052	+ 0·285	+ 0·337	+ 0·337	63°	0·056	+ 0·275	+ 0·331	+ 0·331
34	0·053	+ 0·284	+ 0·337	+ 0·337	75	0·058	+ 0·270	+ 0·328	+ 0·329
53	0·055	+ 0·278	+ 0·333	+ 0·333	91	0·061	+ 0·263	+ 0·324	—

EXPERIMENTAL.

In order to maintain constant temperatures within the range 12·5—91°, a special type of thermostat was constructed. It consisted of two concentric copper cylinders and, in the space between their walls, were placed liquids boiling at the desired temperatures. The cylinders were covered by means of a copper ring, and a long reflux condenser was inserted in a hole in the top. The apparatus was heated by gas. Water in the central cylinder was mechanically stirred. Around the walls of the inner vessel a copper coil was placed through which hydrogen circulated before passing into the hydrogen electrodes. The cell was almost completely immersed in the water, and the inner tank was covered except for holes for a thermometer and the various tubes employed.

In carrying out *E.M.F.* measurements, it was essential that the hydrogen should be pre-heated to the correct temperature before being introduced into the hydrogen electrode vessels, and that it should be saturated with water vapour at each particular temperature. This was accomplished by allowing it to bubble very slowly through two bottles of water, placed in the tank, before passing to the electrodes. Had this not been done, serious errors due to evaporation of the solution in the hydrogen electrode chamber would have occurred.

Another source of error lies in the increased diffusion of electrolytes at elevated temperatures. This was most likely to happen by the potassium chloride diffusing from the salt bridge to the N-calomel electrode, and consequently, instead of allowing the tube from this electrode to dip into a saturated solution of potassium chloride, it was dipped into N-potassium chloride solution, which, in turn, was connected with a vessel containing the saturated solution. Diffusion of the salt from the salt bridge into the 0·08N-hydrochloric acid solution in the hydrogen electrode vessel was also likely to occur, and this would have influenced the potential of the electrode (" salt effect "). This was eliminated as far as possible by the interposition of a vessel containing 0·08N-hydrochloric acid between the salt bridge and the hydrogen electrode. The actual lay-out of the cell system used was therefore

$$\overset{-}{H_2} \mid 0\cdot08N\text{-HCl} \mid 0\cdot08N\text{-HCl} \mid \text{Satd. KCl} \mid N\text{-KCl} \mid N\text{-KCl};\ Hg_2Cl_2 \mid \overset{+}{Hg}$$

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390. *The Standardisation of some Buffer Solutions at Elevated Temperatures.*

By H. T. S. BRITTON and GEORGE WELFORD.

This paper records measurements of the p_H *values at* 12·5°, 25°, 34°, 53°, 63°, 75° and 91° for the Britton–Robinson universal buffer mixture and also for buffer solutions obtained by the separate neutralisation of the constituent acids, *viz.*, citric, diethylbarbituric, and boric acid and potassium dihydrogen phosphate. The dissociation constants of the acids have been calculated at the different temperatures, and the results discussed.

SAVE for the work of Walbum (*Biochem. Z.*, 1920, **107**, 219), who determined the p_H values of some of Sørensen's buffer solutions (*ibid.*, 1909, **21**, 131; **22**, 352; *Ergebn. Physiol.*, 1912, **12**, 393) at temperatures varying from 10° to 70°, and of Kolthoff and Tekelenburg

(*Rec. trav. chim.*, 1927, **46**, 33; Kolthoff, "Saure-Basen Indicatoren," 4th ed., 1932, p. 251 *et seq.*), who also investigated buffer mixtures between 10° and 60°, little seems to have been done to ascertain the usefulness of buffer mixtures at elevated temperatures, and this is particularly true of universal buffer mixtures such as might be used to calibrate the glass electrode. As it was desired to determine the p_H values of solutions at elevated temperatures by means of the glass electrode, it was necessary to find the p_H values corresponding to different stages of neutralisation of a buffer mixture which extended over a wide p_H range. Prideaux and Ward's universal buffer mixture (J., 1924, **125**, 426) was first considered, but had the serious disadvantage that one of its constituents, *viz.*, phenylacetic acid, is appreciably volatile at the higher temperatures; Prideaux's earlier buffer mixture (*Proc. Roy. Soc.*, 1916, **92**, *A*, 463), in which acetic acid is used, is still more disadvantageous. For use at higher temperatures Britton and Robinson's universal buffer mixture (J., 1931, 1456) was much more satisfactory: now that diethylbarbituric acid can be obtained commercially, there is no need to use the sodium salt and an equivalent amount of hydrochloric acid in preparing the mixture. All the constituents can therefore be weighed out directly, and it thus becomes a solution which is 0·02857M. with respect to each of its four constituents.

For work within smaller p_H ranges buffer solutions were prepared from each of the constituents separately, and the p_H values found when they were treated with increasing amounts of sodium hydroxide at various temperatures. 0·2N-Solutions of potassium dihydrogen phosphate, citric acid, and boric acid were used, but owing to its low solubility diethylbarbituric acid was used in 0·03N-solution.

EXPERIMENTAL.

The apparatus described in the preceding paper was employed, and the hydrogen was saturated with water vapour at each temperature before being passed very slowly through the hydrogen electrode. The pressure of hydrogen, P, surrounding the electrode was therefore equal to 1 atm. minus the saturated vapour pressure of water, p, and consequently $P = (760 - p)/760$ atm. The *E.M.F.* of the cell

$$\overset{+}{\text{N-Calomel}} \;\Big|\; \text{N-KCl} \;\Big|\; \text{Satd. KCl} \;\Big|\; 100 \text{ c.c. Buffer mixture} + x \text{ c.c. } 0{\cdot}2\text{N-NaOH} \;\Big|\; \overset{-}{H_2}$$

$$= E_{N\text{-Cal.}} - E_{H_2} = E_{N\text{-Cal.}} - \boldsymbol{R}T/\boldsymbol{F} \log_e [H^{\cdot}]/\sqrt{P}$$
$$= E_{N\text{-Cal.}} + \tfrac{1}{2} \times 0{\cdot}0001984T.\log P + 0{\cdot}0001984T \times p_H$$

The values, $E_{N\text{-Cal.}}$, are those recorded by the authors (*loc. cit.*).

The data are given in Table I, and those of the universal buffer mixture are plotted in the figure, Britton and Robinson's original data for 18° being plotted as a broken line. It will be seen that, as the temperature is increased, the p_H values vary but little until p_H 6 is reached. Thereafter they becomes considerably lower as the temperature increases, the curves exhibiting marked departure from the rectilinearity characteristic of that at ordinary temperatures. The upper scale of the figure indicates when the different acids or acid stages undergo neutralisation with sodium hydroxide. The p_H values during the addition of the first 3 equivs. of alkali, corresponding with the neutralisation of the three stages of citric acid, change but little with temperature. This effect is seen more clearly in Table I (i), the first 42·9 c.c., and in Table I (ii), the reason being that temperature has but a slight influence on each of the three dissociation constants (Table II). Table II (i) gives the p_H values set up at the mid-points of neutralisation of each of the successive stages of neutralisation of 0·2N-citric acid [Table I (ii)], and on the assumption that these values are approximately those of p_{K_1}, p_{K_2}, and p_{K_3} respectively, it will be seen that, whereas K_1 and K_2 are almost constant, K_3 becomes somewhat smaller with rising temperature. In the remaining sections of Table II, the classical p_K values of the second and third stages of phosphoric acid and of boric and diethylbarbituric acids are given. They were calculated from Table I, (iii)—(v). The data reveal that, except for the ionisation $H_2PO_4{}' \rightleftharpoons H^{\cdot} + HPO_4{}''$, which appears scarcely to be influenced by temperature, the constants increase with temperature. (The constants calculated from p_H data set up during the first half of the neutralisation of boric acid are a little larger than those referring to the second half, a difference which becomes less apparent at the higher temperatures.) These enhanced constants explain why the curves referring to the addition of the last 4 equivs. of alkali to the universal

TABLE I.

x.	(i) Britton–Robinson universal buffer mixture. 12·5°.	25°.	34°.	53°.	63°.	75°.	91°.	(ii) 0·2N-Citric acid. 12·5°.	25°.	34°.	53°.	63°.	75°.	91°.
0	2·38	2·42	2·47	2·53	2·55	2·59	2·64	2·12	2·13	2·13	2·14	2·14	2·14	2·14
5	2·86	2·90	2·92	2·94	2·94	2·96	2·96	2·43	2·43	2·43	2·44	2·44	2·44	2·44
10	3·36	3·36	3·36	3·35	3·35	3·35	3·35	2·70	2·70	2·70	2·70	2·70	2·70	2·70
15	3·94	3·92	3·89	3·85	3·84	3·83	3·82	2·93	2·93	2·93	2·93	2·93	2·93	2·93
20	4·42	4·40	4·37	4·35	4·34	4·33	4·33	3·15	3·15	3·15	3·15	3·15	3·15	3·15
25	4·83	4·82	4·80	4·80	4·80	4·80	4·80	3·37	3·37	3·37	3·37	3·37	3·37	3·37
30	5·25	5·27	5·28	5·28	5·30	5·31	5·33	3·59	3·59	3·60	3·60	3·60	3·60	3·60
35	5·65	5·68	5·70	5·73	5·74	5·76	5·75	3·82	3·83	3·83	3·83	3·83	3·83	3·83
40	6·10	6·10	6·10	6·10	6·10	6·10	6·10	4·04	4·05	4·05	4·05	4·05	4·06	4·06
45	6·55	6·51	6·49	6·47	6·46	6·45	6·44	4·27	4·27	4·27	4·27	4·27	4·28	4·28
50	6·96	6·90	6·85	6·80	6·77	6·73	6·71	4·44	4·44	4·45	4·46	4·46	4·47	4·47
55	7·38	7·30	7·24	7·15	7·09	7·02	6·98	4·64	4·64	4·64	4·65	4·65	4·67	4·69
60	7·82	7·71	7·61	7·48	7·42	7·33	7·27	4·82	4·85	4·87	4·87	4·87	4·88	4·92
65	8·27	8·14	8·01	7·87	7·76	7·67	7·59	5·00	5·05	5·05	5·07	5·08	5·13	5·18
70	8·77	8·63	8·48	8·35	8·25	8·16	8·07	5·21	5·25	5·28	5·32	5·34	5·36	5·42
75	9·30	9·15	9·01	8·87	8·77	8·67	8·58	5·43	5·47	5·48	5·54	5·56	5·61	5·68
80	9·90	9·71	9·55	9·40	9·30	9·16	9·06	5·65	5·67	5·69	5·75	5·78	5·83	5·90
85	10·90	10·50	10·27	10·06	9·93	9·77	9·57	5·85	5·89	5·90	5·96	6·00	6·06	6·13
90	11·60	11·25	11·02	10·68	10·48	10·24	9·95	6·11	6·14	6·16	6·24	6·25	6·33	6·40
95	11·91	11·58	11·36	10·98	10·77	10·51	10·17	6·46	6·50	6·52	6·61	6·67	6·71	6·84
100	12·10	11·79	11·56	11·14	10·97	10·69	10·34	—	—	—	—	—	—	—

x.	(iii) 0·2N-KH_2PO_4. 12·5°.	25°.	34°.	53°.	63°.	75°.	91°.	(iv) 0·03N-Diethylbarbituric acid.* 12·5°.	25°.	34°.	53°.	63°.	75°.	91°.
5	5·86	5·86	5·86	5·86	5·86	5·86	5·86	6·78	6·61	6·51	6·35	6·25	6·13	5·99
10	6·21	6·21	6·21	6·20	6·20	6·20	6·20	7·08	6·95	6·86	6·67	6·56	6·47	6·28
15	6·45	6·44	6·42	6·42	6·42	6·42	6·40	7·27	7·16	7·05	6·89	6·74	6·64	6·47
20	6·64	6·64	6·62	6·62	6·62	6·62	6·61	7·42	7·32	7·21	7·01	6·90	6·79	6·62
25	6·82	6·81	6·80	6·80	6·80	6·80	6·79	7·56	7·44	7·33	7·14	7·03	6·91	6·73
30	6·99	6·98	6·98	6·98	6·98	6·98	6·97	7·66	7·52	7·43	7·25	7·11	7·01	6·84
35	7·17	7·17	7·16	7·16	7·15	7·15	7·15	7·73	7·63	7·53	7·33	7·22	7·11	6·93
40	7·41	7·40	7·39	7·38	7·38	7·38	7·38	7·84	7·72	7·63	7·44	7·30	7·20	7·02
45	7·75	7·75	7·74	7·74	7·74	7·74	7·74	7·91	7·81	7·74	7·52	7·39	7·28	7·11
50	9·23	9·26	9·24	9·16	9·10	9·00	8·94	8·02	7·91	7·79	7·59	7·47	7·37	7·19
55	10·84	10·74	10·61	10·37	10·23	10·07	9·84	8·10	7·97	7·90	7·67	7·56	7·45	7·27
60	11·19	11·06	10·93	10·68	10·53	10·36	10·11	8·17	8·08	7·97	7·78	7·65	7·53	7·35
65	11·43	11·27	11·13	10·88	10·71	10·53	10·29	8·27	8·15	8·06	7·87	7·73	7·61	7·45
70	11·58	11·45	11·28	10·99	10·83	10·66	10·39	8·38	8·26	8·15	7·94	7·82	7·71	7·54
75	11·74	11·56	11·41	11·10	10·92	10·75	10·49	8·48	8·36	8·25	8·05	7·93	7·84	7·66
80	11·87	11·68	11·51	11·18	11·01	10·84	10·55	8·58	8·47	8·34	8·18	8·08	7·96	7·80
85	11·98	11·78	11·61	11·26	11·09	10·89	10·63	8·72	8·61	8·48	8·33	8·21	8·09	7·94
90	12·10	11·87	11·69	11·33	11·15	10·95	10·67	8·88	8·79	8·69	8·52	8·38	8·26	8·11
95	12·20	11·98	11·76	11·38	11·20	11·00	10·71	9·20	9·06	8·93	8·77	8·67	8·52	8·35
100	12·27	12·02	11·82	11·44	11·24	11·04	10·74	—	—	—	—	—	—	—

(v) 0·2N-HBO_2.

x.	12·5°.	25°.	34°.	53°.	63°.	75°.	91°.
5	7·43	7·47	7·46	7·44	7·38	7·37	7·37
10	7·89	7·89	7·86	7·81	7·75	7·74	7·73
15	8·19	8·15	8·12	8·05	8·00	7·98	7·94
20	8·41	8·38	8·32	8·27	8·19	8·14	8·11
25	8 61	8·55	8·48	8·42	8·36	8·31	8·26
30	8·75	8·69	8·65	8·55	8·47	8·45	8·37
35	8·91	8·85	8·77	8·67	8·61	8·56	8·49
40	9·04	8·97	8·89	8·77	8·71	8·66	8·58
45	9·16	9·08	8·99	8·89	8·81	8·76	8·68
50	9·27	9·18	9·10	8·97	8·91	8·86	8·76
55	9·38	9·29	9·20	9·09	8·99	8·96	8·86
60	9·48	9·37	9·31	9·18	9·10	9·04	8·94
65	9·59	9·48	9·39	9·28	9·20	9·15	9·04
70	9·68	9·59	9·50	9·39	9·31	9·23	9·15
75	9·77	9·68	9·59	9·49	9·41	9·34	9·25
80	9·91	9·81	9·72	9·62	9·54	9·47	9·36
85	10·06	9·95	9·89	9·78	9·68	9·60	9·49
90	10·21	10·14	10·03	9·91	9·83	9·75	9·64
95	10·52	10·40	10·32	10·16	10·07	9·93	9·80
100	—	—	—	—	—	—	—

* 0·03N-NaOH used for titration.

buffer mixture are depressed as the temperature is increased. *The fact that the curves begin to diverge with the addition of the fourth equiv. is evidently due to incipient neutralisation of* diethylbarbituric acid.

The very slight effect of temperature on the three dissociation constants of citric acid explains why Kolthoff and Tekelenburg (*loc. cit.*) observed that temperatures up to 60° led to an almost negligible variation in the p_H values of mixtures involving disodium hydrogen citrate, whilst the increase in K_3 of phosphoric acid accounts for the appreciable lowerings in the p_H values of disodium hydrogen phosphate–sodium hydroxide buffer mixtures at temperatures up to

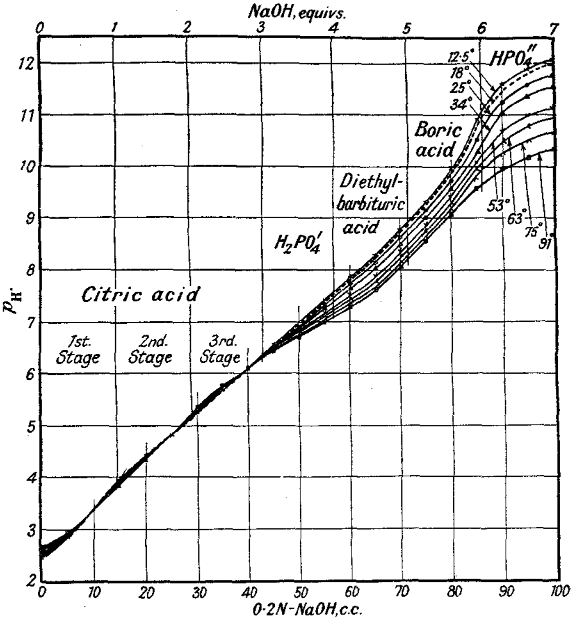

TABLE II.

(i) p_H Values at 0·5, 1·5, and 2·5 equivs. of NaOH per mol. of citric acid.

NaOH, mols.	12·5°.	25°.	34°.	53°.	63°.	75°.	91°.
0·5	3·01	3·01	3·01	3·01	3·01	3·01	3·01
1·5	4·44	4·44	4·45	4·46	4·46	4·47	4·49
2·5	5·78	5·81	5·84	5·90	5·94	5·99	6·06

(ii) $p_{K_2(\text{class.})}$ for $H_2PO_4' \rightleftharpoons H^{\cdot} + HPO_4''$.

Neutn., %.	12·5°.	25°.	34°.	53°.	63°.	75°.	91°.
30	6·82	6·81	6·79	6·79	6·79	6·79	6·77
50	6·82	6·81	6·80	6·80	6·80	6·80	6·79
70	6·80	6·80	6·79	6·79	6·78	6·78	6·78

(iii) $p_{K_3(\text{class.})}$ for $HPO_4'' \rightleftharpoons H^{\cdot} + PO_4'''$.

25	11·85	11·71	11·64	11·47	11·46	11·41	11·32
50	11·84	11·71	11·62	11·52	11·43	11·41	11·36
75	11·85	11·66	11·60	11·51	11·46	11·38	11·37

(iv) $p_{K(\text{class.})}$ for $HBO_2 \rightleftharpoons H^{\cdot} + BO_2'$.

25	9·09	9·03	8·96	8·90	8·84	8·79	8·74
50	9·27	9·18	9·10	8·97	8·91	8·86	8·76
75	9·29	9·20	9·11	9·01	8·93	8·86	8·77

(v) $p_{K(\text{class.})}$ for diethylbarbituric acid.

25	8·04	7·92	7·81	7·62	7·51	7·39	7·21
50	8·02	7·91	7·79	7·59	7·47	7·37	7·19
75	8·00	7·88	7·77	7·57	7·45	7·36	7·18

60°. The gradual increase in the dissociation of boric acid with temperature similarly accounts for the lower p_H values indicated by Walbum's borax mixtures at elevated temperatures.

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WASHINGTON SINGER LABORATORIES, UNIVERSITY COLLEGE, EXETER. [*Received, July 15th, 1937.*]

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391. *The Reaction of* tert.*-Butyl Chloride with Formic Acid:* tert.*-Butyl Formate.*

By WILLIAM TAYLOR.

The interpretation offered by Bateman and Hughes (this vol., p. 1187) for the constant rate of reaction of water, *tert.*-butyl chloride, and formic acid (solvent) to give *tert.*-butyl alcohol is shown to be inadequate, since they did not take into account the formation of *tert.*-butyl formate. An alternative explanation of their kinetic results is based on this fact, *viz.*, that *tert.*-butyl chloride reacts with the formic acid to give *tert.*-butyl formate.

THE mechanism of hydrolysis of certain types of alkyl halides such as *tert.*-butyl halides was assumed by Hughes and Ingold (J., 1935, 244), on indirect evidence, to be unimolecular, with water playing the part of ionising medium; for others, such as methyl and ethyl halides, it was assumed to be bimolecular. The author (this vol., p. 344) on the other hand has assumed, also on indirect evidence, that for alkyl halides generally, the mechanism is the same and is bimolecular, with water acting as a direct reagent. Recently, Bateman and Hughes (this vol., p. 1187) presented what purports to be direct evidence in support of the ionisation mechanism, *viz.*, that the rate of reaction of *tert.*-butyl chloride with water in formic acid is of the first order, and independent of the (small) concentration of water. The kinetic results, obtained by measuring the rate of formation of hydrogen chloride by a modified Volhard method, apparently therefore show the mechanism of hydrolysis to be unimolecular, but only because they are based on the assumption that the primary reaction is between the *tert.*-butyl chloride and water. Seeing that these authors were unable to isolate *tert.*-butyl formate when using Kahlbaum's formic acid, and only *tert.*-butyl alcohol from the aqueous acid, this assumption was justified. However, it can no longer be maintained, since tert.*-butyl formate* has now been isolated from Kahlbaum's formic acid and *tert.*-butyl chloride at room temperature. The reaction (E) under these conditions being reversible, and the forward reaction normally taking place to the extent of only about 19% (Bateman and Hughes, *loc. cit.*), the equilibrium was pushed over to the right by having present an excess of powdered calcium formate. *tert.*-Butyl formate is hydrolysed almost instantaneously by aqueous alkali and extremely rapidly by hydrochloric acid even in a heterogeneous system. It is mainly to this ease of hydrolysis that Bateman and Hughes's failure to isolate the ester must be attributed, for in order to extract the end-products they added water to the reaction mixture before adding the organic solvent, ether or carbon tetrachloride.

From the foregoing, an alternative explanation of the kinetic results is possible, which briefly is that the primary reaction is bimolecular:

$$Bu^{\gamma}Cl + H\cdot CO_2H \rightleftharpoons H\cdot CO_2Bu^{\gamma} + HCl \quad . \quad . \quad . \quad . \quad (E)$$

together with $Bu^{\gamma}Cl + H\cdot CO_2H \rightleftharpoons CMe_2{:}CH_2 + HCl + H\cdot CO_2H$ to a small extent.

The forward reaction would be kinetically of the first order and, for reasons given below, the rate would be for all practical purposes independent of small concentrations of water. The principal obvious effect of water will be to alter the equilibrium position by ionising the hydrogen chloride, as pointed out by Bateman and Hughes, and by causing the partial hydrolysis of the formate. Probably some *tert.*-butyl alcohol is formed by the direct

interaction of *tert.*-butyl chloride and water in formic acid containing small concentrations of water, but this will be a minor reaction, owing to the small concentration of water relative to formic acid, if its rate is either less than or approximately equal to that of the forward reaction in (E). That these two rates are comparable is probable, since the combined rate of alcoholysis and hydrolysis of *tert.*-butyl chloride at 15° in 50% aqueous ethyl alcohol is 1×10^{-4} sec.$^{-1}$ (approx.) (see Hughes, J., 1935, 255) whereas for the forward reaction in (E) the rate at 15° is $3{\cdot}7 \times 10^{-4}$ sec.$^{-1}$ (approx.) (Bateman and Hughes, *loc. cit.*). In other words, in this alternative explanation of the kinetic results of Bateman and Hughes, the view is taken that water and formic acid are approximately equally rapidly effective under these experimental conditions in reacting directly with *tert.*-butyl chloride to produce hydrogen chloride; hence small concentrations of water will not noticeably affect its rate of formation from *tert.*-butyl chloride in formic acid.

Experimental.

Isolation of tert.*-Butyl Formate.*—*tert.*-Butyl chloride (24 g.), Kahlbaum's formic acid (200 c.c.), and finely powdered calcium formate (70 g.) were kept at room temperature in a ground-glass stoppered bottle, with occasional shaking, for 3 days. Ether was then added, and the liquid washed with water till the washings were neutral to phenolphthalein, dried (sodium sulphate), and the ether distilled off; fractional distillation then gave three fractions: (1) b. p. 45—65° (14 g.), (2) b. p. 65—80° (4 g.), (3) b. p. 80—84° (6·5 g.). Redistillation of (2) gave 0·5 g. of b. p. 80—83·5°. Redistillation of this and (3) gave 6·5 g. of b. p. 82·5—83·5°/757 mm. (Found: C, 59·0; H, 9·7. $C_5H_{10}O_2$ requires C, 58·8; H, 9·8%).

Hydrolysis of tert.*-Butyl Formate.*—(*a*) 0·4528 G. of the ester, dropped into 50 c.c. of N/10-aqueous sodium hydroxide, disappeared in less than 1 min. at room temperature; after 5 minutes, back titration with N/10-acid gave *M*, 113·7 (Calc.: 114). (*b*) Hydrochloric acid (10 c.c., N.) hydrolysed the ester (0·5 g.) completely at room temperature during 10 mins.' shaking, as shown by the entire disappearance of the oily drops. (*c*) Water alone (5 c.c.) hydrolysed the ester (0·5 g.) completely at room temperature in 3 days, with occasional shaking.

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392. *Direct Evidence in Support of a Bimolecular Mechanism for the Hydrolysis of* tert.*-Alkyl Halides: The Hydrolysis of* tert.*-Butyl Bromide in Acetone.*

By William Taylor.

Two items of direct evidence in support of a bimolecular mechanism for the hydrolysis of *tert.*-alkyl halides, obtained by investigating the hydrolysis of *tert.*-butyl bromide in acetone containing small concentrations of water, are: (1) that for the lowest concentrations of water studied, *viz.*, "1%" and "2%," when the effects of these concentrations on the properties of the solvent are probably similar, the second-order velocity coefficients are almost the same; and (2) that for all the concentrations of water studied—"1%" to "10%"—the equilibrium positions calculated, on the assumption of second-order velocity coefficients for both forward and reverse reactions, are almost identical with those observed.

From indirect evidence, the author has assumed (this vol., pp. 344, 992) that the mechanism of hydrolysis and alcoholysis of alkyl halides, generally, is bimolecular. This is contrary to the views of Hughes and Ingold (J., 1935, 244), who, according to their ionisation mechanism, regard the hydrolysis of *tert.*-alkyl halides as being unimolecular. If the former view be correct, then, in an inert solvent and for the same molecular concentration of alkyl halide throughout, with small concentrations of water the rate of hydrolysis should be directly proportional to the concentration of water. The object of the present investigation was to find whether this were the case or not, and, in fact, the evidence supports a bimolecular mechanism.

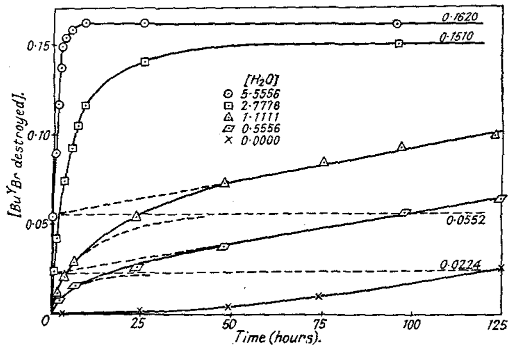
tert.-Butyl bromide was chosen as the alkyl halide for two reasons, chiefly because it

was known to be reactive enough to give measurable rates of hydrolysis even with low concentrations of water, and also because the mechanism has been problematical especially in the case of *tert.*-alkyl halides. Acetone was chosen as the solvent since it is non-hydroxylic and could therefore be regarded as being inert to *tert.*-butyl bromide. The considerable difficulties attending the use of this solvent were overcome.

The rates of hydrolysis were measured at 50° with 1, 2, 5, and 10 g. of water in 100 c.c. of acetone solution containing the same concentration of *tert.*-butyl bromide in each case. (These solutions are referred to as containing "1%," "2%," etc., of water.) The plot of the molar concentration of *tert.*-butyl bromide hydrolysed (x) against time (see figure) shows the dependence of the rate of hydrolysis upon the concentration of water even at the lowest concentrations. The reaction involved, since water gives little or no olefin with *tert.*-butyl bromide (forthcoming communication), is

$$\mathrm{Bu^{\gamma}Br + H_2O \underset{k_2}{\overset{k_1}{\rightleftharpoons}} Bu^{\gamma}OH + HBr}$$

and is reversible, but, as can be seen from the figure, a slow reaction persisted beyond the equilibrium position. The increase in acidity produced by this reaction was almost



directly proportional to time, at least for a considerable time interval, and in this respect it was similar to the slow reaction observed by Baker and Nathan (J., 1936, 236) during the reversible reaction between 2 : 4-dinitrobenzyl bromide and benzylpyridinium nitrate in dry acetone. Hence, as in this case, the equilibrium position for any one system was determined by extrapolation of the straight-line portion of the curve back to the x axis. By determining the rates of the reverse reaction with the same initial concentrations of water as those already stated, and accepting only the earlier values of the second-order rate constants for both reactions, the equilibrium constants $K = k_1/k_2$ were obtained for the three smallest concentrations of water. From these values of K the equilibrium positions could be calculated with the aid of Bennett and Mosses' equation (J., 1931, 2957):

$$n = \frac{K(a+b) + (c+d) - \sqrt{[K(a+b)+c+d]^2 - 4(abK - cd)(K-1)}}{2(K-1)}$$

where n is the equilibrium value of x. The values of n were calculated for the forward reaction only, *i.e.*, when $c = d = 0$, since the reverse reaction is retarded with extreme ease by small concentrations of water, as can be seen from the fall in the value of k_2 during any one run and from the great differences in the initial values at the different water concentrations (see also Norris, *Z. physikal. Chem.*, **1927**, **130**, 660; *Rec. trav. chim.*, **1929**,

48, 885; Levene and Rothen, *J. Biol. Chem.*, 1929, **81**, 359), and therefore no reliance could be placed on the lowest acid concentration reached in this reaction (see below also). The calculated and the observed values of n are almost identical (Table I) and this constitutes a sound argument for the validity of the assumption made, *viz.*, that *both* reactions are kinetically of the second order. A further piece of direct evidence that the hydrolysis reaction is kinetically of this order is that, with the two lowest water concentrations, where the effect of the water may be taken to alter the general solvent properties of the medium to a similar extent, the second-order values of k_1 are nearly the same. That water has an accelerating solvent effect on the hydrolysis is undoubted from the values of k_1 with the higher concentrations of water (Table I). It might therefore be argued that, in accordance with the ideas of Hughes and Ingold, the increase in k_1 if this were calculated on a first-order basis is due to the effect of the increased ionising powers of the solvent medium on *tert.*-butyl bromide. If so, it would be a coincidence to have such direct proportionality between water concentration and ionising powers as would thereby be held to be exhibited by acetone containing 1% and 2% of water. From this evidence, then, it is contended that the mechanism of hydrolysis of *tert.*-butyl bromide is bimolecular; and the same is held to be true for *tert.*-alkyl halides in general.

TABLE I.

Showing the practical identity of observed and calculated values of n, the equilibrium position, it being assumed that both reactions are kinetically of the second order.

$[Bu^{\gamma}Br] = 0{\cdot}1620$.

G. of H_2O per 100 c.c. of soltn. at 50°.	$[H_2O.]$	2nd-Order k_1.	k_1.*	2nd-Order k_2.	K.	n (obs.).	n (calc.).
1	0·5556	0·0291	0·0337	3·96	0·00735	0·0224	0·0233
2	1·1111	0·0311	0·0324	1·08	0·0288	0·0552	0·0558
5	2·7778	0·0599	—	0·0581	1·03	0·1510	0·1500
10	5·5556	0·184	—	0·000	∞	0·1620	0·1620

* Calculated from n (obs.) and Baker and Nathan's formula (*loc. cit.*) for a bimolecular reversible reaction where the initial concentrations of the reactants are different.

The cause of the continued slow development of acidity in the hydrolysis experiments was the formation of mesityl oxide, phorone, and other unidentified acetone condensation products in the presence of hydrogen bromide. This caused the elimination of water, and hence continued hydrolysis of *tert.*-butyl bromide. The amount of water formed in this way during the reverse reaction was so large as not only greatly to retard the formation of *tert.*-butyl bromide in all except the initial stages, but ultimately even to cause the slow hydrolysis of that already formed, as shown by the rapid decrease in acidity giving place to a slow increase [Table II (b)].

EXPERIMENTAL.

The *tert.*-butyl bromide was from the same stock as before (this vol., p. 992); the *tert.*-butyl alcohol had m. p. 25°. "AnalaR" Acetone, dried over sodium sulphate, was first employed, but it was found that, when hydrobromic acid (2 c.c., *d* 1·5) was added to 100 c.c. of this acetone, there was at 50° a gradual disappearance of acidity during approximately 1 hour. An attempt to remove any hydroxylic impurity by refluxing over and distilling from sodium did not overcome this difficulty, nor did purification according to Conant and Kirner (*J. Amer. Chem. Soc.*, 1924, **46**, 246), whose method, however, was applied to "AnalaR" acetone to obtain the solvent used in the kinetic experiments.

In the experiments on the reaction of hydrogen bromide with *tert.*-butyl alcohol, a correction was applied for this removal of acidity in solutions containing initially 1% and 2% of water by performing control experiments with no *tert.*-butyl alcohol present. No correction was necessary with other solutions. The dark brown colour that developed in all solutions, made to examine either forward or reverse reactions, was also observed when hydrogen bromide was present alone in aqueous acetone containing the same proportions of water. Presumably the colour was due to the condensation of the acetone under the influence of hydrogen bromide.

Flasks were calibrated to hold at 20° that volume of acetone which at 50° became 100 c.c., and pipettes were calibrated for 5 or 10 c.c. under the same conditions. In making up the reaction mixtures, measured volumes of water and *tert.*-butyl bromide or of water, hydrobromic

acid (*d* 1·5), and *tert.*-butyl alcohol were put into acetone at 20° in a calibrated flask, and diluted to the mark with acetone. Aliquot portions were immediately pipetted into steamed and dried tubes, which were then put into ice, hermetically sealed, and placed for protection in stout, fairly tightly-fitting tubes in a thermostat at 50°. The temperature of the bath was attained after immersion for 3 minutes, and this was taken as zero time.

To follow the appearance or disappearance of acidity, at suitable times a tube was broken in *ca.* 100 c.c. of absolute ethyl alcohol (previously rendered very faintly alkaline to phenolphthalein) contained in a stoppered bottle. The liquid was titrated with N/10-sodium hydroxide or N/10-hydrochloric acid. As the reaction liquid became darker, it was more difficult but not impossible to ascertain the end-point.

Since only the initial values of the velocity coefficients k_1 and k_2 could be relied on, owing chiefly to the formation of water caused by the condensation of the acetone, these were sufficiently accurate when calculated from the equation for an irreversible second-order reaction

$$k = [2{\cdot}303/t(a - b)] \log_{10}[b(a - x)/a(b - x)]$$

t being the time in hours, and a and b the concentrations (in g.-mols./l.) of water and *tert.*-butyl bromide respectively in the forward reaction, and of *tert.*-butyl alcohol and hydrogen bromide respectively in the reverse reaction. However, for the forward reaction in acetone containing 1% and 2% of water, Baker and Nathan's equation (*loc. cit.*) for a bimolecular reversible reaction was also applied in conjunction with the observed values of n for the equilibrium position (see Table II).

TABLE II.

(a) *Details of experiments on the forward reaction.*

b = 0·1620 throughout.

Expt. 1; a = 5·5556.

t.	x.	k_1.	t.	x.	k_1.
0·40	0·0530	0·180	2·90	0·1528	0·181
0·85	0·0902	0·174	4·57	0·1580	—
1·33	0·1180	0·179	7·78	0·1625	—
1·78	0·1378	0·195	25	0·1620	—
2·37	0·1490	0·195	96	0·1620	—

Expt. 2; a = 2·7778.

t.	x.	k_1.	t.	x.	k_1.
0·95	0·0236	0·0599	6·6	0·1060	0·0593
1·90	0·0426	0·0583	8·25	0·1170	0·0587
3·63	0·0740	0·0614	25	0·1410	(0·0298)
5·02	0·0936	0·0630	96·5	0·1510	—

Expt. 3; a = 1·1111.

t.	x.	k_1.	k_1.*	t.	x.
2·0	0·0112	0·0326	0·0327	75	0·0850
4·0	*0·0216*	*0·0326*	*0·0338*	*98*	*0·0960*
6·6	0·0298	0·0281	0·0306	119	0·1000
24	0·0540	(0·0156)	—	286	0·1290
48	0·0742	(0·0124)	—		

Expt. 4; a = 0·5556.

t.	x.	k_1.	k_1.*	t.	x.
3·0	0·0080	0·0299	0·0318	99	0·0562
7·0	*0·0166*	*0·0282*	*0·0357*	*120*	*0·0640*
24	0·0256	(0·0132)	—	175	0·0856
48	0·0380	(0·0104)	—	287	0·1074

(b) *Details of experiments on the reverse reaction.*

Expt. 5; a = 0·2077, b = 0·1730, [H_2O] = 5·5556.

t.	$b - x$.	t.	$b - x$.
0·20	0·1725	25·0	0·1735
0·50	0·1730	241	0·1730
7·0	0·1730	624	0·1735

Expt. 6; a = 0·2077, b = 0·1730, [H_2O] = 2·7778.

t.	$b - x$.	k_2.	t.	$b - x$.
0·20	0·1730	—	24	0·1610
0·80	0·1710	0·0664	51	0·1610
6·4	0·1620	0·0498	240	0·1630

Expt. 7; a = 0·2077, b = 0·1730, [H_2O] = 1·1111.

t.	$b - x$.	δx.*	$b - x$ (corr.).	k_2.
0·1	0·1672	0·0015	0·1687	1·13
0·2	0·1616	0·0034	0·1650	1·13
0·33	0·1556	0·0056	0·1612	1·03
0·67	0·1420	0·0087	0·1507	1·04
1·33	0·1268	0·0120	0·1388	(0·868)
3·33	0·1022	,,	0·1142	(0·712)
5·25	0·0934	,,	0·1054	(0·558)
26	0·0850	,,	0·0970	(0·140)
51	0·0954	,,	0·1074	—
215	0·1290	,,	0·1410	—

Expt. 8; a = 0·1038, b = 0·0865, [H_2O] = 0·5556.

t.	$b - x$.	δx.*	$b - x$ (corr.).	k_2.
0·1	0·0816	0·0014	0·0830	3·99
0·18	0·0774	0·0032	0·0806	3·92
0·33	0·0740	0·0047	0·0787	(2·86)
0·67	0·0672	0·0076	0·0748	(2·23)
1·17	0·0574	0·0100	0·0674	(2·28)
3·0	0·0436	0·0115	0·0551	(1·74)
6·7	0·0364	,,	0·0479	(1·09)
27	0·0254	,,	0·0369	(0·43)
52	0·0300	,,	0·0415	—
216	0·0510	,,	0·0625	—

* δx is the correction applied for the removal of acidity by acetone itself, containing initially hydrogen bromide and water of the given concentrations.

An experiment with *tert.*-butyl bromide and dry acetone recorded below appears to indicate that even very small traces of moisture, possibly in the air in the sealed tubes, caused elimination

of hydrogen bromide. (Alternatively, even dry acetone itself may react to this slight extent with *tert.*-butyl bromide.) This in turn caused condensation of the acetone, and hence the formation of water followed by continued hydrolysis of the alkyl bromide. There was thus an "induction period" in the formation of acid (see fig.), followed, after approximately 3 days, by a rate which was almost directly proportional to time.

$a = 0{\cdot}0000$; $b = 0{\cdot}1620$

t	0	6	24	49	74	125	262	383
$10^4 x$	—	—	20	60	100	260	680	1000

Attempts to ascertain the proportions of olefin formed from *tert.*-butyl bromide by the procedure adopted previously (this vol., p. 344) failed, since, with the lower concentrations of water, over 100% olefin was indicated. This was undoubtedly due to the formation of unsaturated compounds such as mesityl oxide.

Isolation and Identification of Mesityl Oxide and Phorone.—(a) *Dry hydrogen bromide and acetone.* Dry hydrogen bromide was passed through ice-cold acetone until the acidity was approximately N. The liquid (100 c.c.) was maintained at 50° for 48 hours; water was added, and the liquid extracted with ether. Distillation gave fractions: (1) b. p. 120—150° (3·7 g.), (2) b. p. 150—195° (1·5 g.). About 4 g. of deep brown tarry liquid remained.

(b) *tert.-Butyl alcohol, hydrogen bromide, and acetone.* The alcohol (4·5 g.) in acetone (150 c.c.), containing hydrogen bromide of the same concentration as in (a), was maintained at 50° for 48 hours, then shaken with water to destroy all butyl bromide, extracted with ether, and distilled; three fractions were obtained: (1a) b. p. 60—120° (4·1 g.), (1) b. p. 120—150° (5·1 g.), (2) b. p. 150—195° (1·1 g.). Some dark tarry liquid (3·6 g.) remained.

(c) tert.-*Butyl bromide, water, and acetone. tert.*-Butyl bromide (6 g.) and water (1 g.) in acetone (100 c.c.) were treated as in (b). The fractions were: (1a) b. p. 60—120° (1·5 g.), (1) b. p. 120—150° (1·6 g.), (2) b. p. 150—200° (0·6 g.), and undistilled tarry liquid (2·0 g.) remained.

(d) *Examination of fractions from* (a), (b), *and* (c). (i) In each case a few drops of fraction (1) in ethyl-alcoholic solution yielded considerable amounts of the carmine-coloured 2 : 4-dinitrophenylhydrazone of mesityl oxide (m. p. and mixed m. p. with authentic specimen).

(ii) Phorone was identified through its tetrabromide (m. p. and mixed m. p. with authentic specimen), isolated according to Claisen (*Annalen*, 1876, **180**, 12), and was present in small quantities in all fractions (2). It was necessary to leave the brominated mixture at room temperatures for 2 weeks to allow the tetrabromide to crystallise from the preponderating amount of oil (presumably mesityl oxide dibromide) also present.

(iii) Attempted oxidation of fractions (2) with alkaline permanganate failed to afford any trimesic acid, so mesitylene was absent.

THE POLYTECHNIC, REGENT STREET, LONDON, W. 1. [*Received, October 16th*, 1937.]

NOTES.

Molecular Solution Volumes of Optical Isomers. By WILLIAM H. BANKS.

PATTERSON and LAMBERTON (this vol., p. 1453) compare molecular solution volumes derived from density measurements on solutions of the optically active isomers of *iso*butyl tartrate. The differences obtained for their solutions in *l*-menthyl acetate are of the order of 0·05 c.c. and are considered to be significant, being several times as great as the probable error of experiment. A consideration of the experiment shows, however, that these differences may be of the same order as error arising from temperature uncertainty.

The effect of uncertainties in density Δd_2 and concentration Δp on the molecular solution volume ϕ may be derived from the authors' equation and is (in their nomenclature)

$$\Delta\phi = \pm 100M \,.\, \Delta d_2/pd_2^2 \mp 100M\{1/d_1 - 1/d_2\}\Delta p/p^2$$

which on substitution of appropriate quantities ($M = 262$; $p = 5{\cdot}5\%$, say; $d_1 = 0{\cdot}925$, $d_2 = 0{\cdot}932$) becomes

$$\Delta\phi = \pm\, 5483\Delta d_2 \mp 7{\cdot}06\Delta p.$$

It is clear that errors in p of 10^{-3} and less (the authors record values to four decimal places) need not be considered. An uncertainty in density, however, of 1×10^{-5} must produce an uncertainty in ϕ of 0·055 c.c. In reference to the second and more accurate series of measure-

ments it is stated that most interpolated values for the temperature 20° were within 1×10^{-5} unit of a mean density–temperature line. That this order of accuracy may reasonably be considered the limit is to be expected from possible temperature uncertainties. A calculation from the authors' data indicates that the *l*-menthyl acetate solutions have a temperature coefficient of about 8×10^{-4} unit/degree, so an uncertainty in temperature of 0·01° will introduce an uncertainty of 8×10^{-6} unit in density. Such an uncertainty in temperature is not unreasonable, since the authors use a thermometer graduated only to 0·05°.

It would seem difficult to attach significance to such consistent differences as are apparent, since these are derived from a comparison of a mean value of only three values for the *l*-isomer with a mean of five for the *d*-isomer, of which one value, VI, is of the same order as those for the *l*-isomer.—BATTERSEA POLYTECHNIC. [*Received, September 30th,* 1937.]

Dipole Moments and Molecular Structure. The Dipole Moments of p-*Hydroxyazobenzene and its Derivatives compared with those of Phenol and its Derivatives.* By FRANK LOUIS WARREN.

THE moments of *p*-hydroxyazobenzene and phenol and their respective derivatives have been compared, for, since azobenzene has zero moment, *p*-hydroxyazobenzene should have the same moment as that of phenol, the moment in both cases being due to the hydroxy-group. The data obtained for *p*-hydroxy- and *p*-methoxy-azobenzene confirm those of Bergmann and Weizmann (*Trans. Faraday Soc.*, 1936, **185**, 1318) and are therefore not given in detail; those for phenyl benzoate and *p*-benzoyloxyazobenzene are tabulated below. The final table shows the close agreement between the moments of the corresponding benzene and azobenzene derivatives, and supports the above authors' conclusion that *p*-hydroxyazobenzene in benzene solution exists almost wholly in the azo-form.

Experimental.—The apparatus used for measuring the dielectric constant was that described by Sugden (J., 1932, 768), with a 210 kc./sec. quartz crystal controlled oscillator in place of the dynatron circuit, and a Sullivan dual-range (65—355; 320—1270 μμ F.) variable air condenser fitted with a double vernier to give a more open scale, as recommended by Sugden. The measuring cell (Farmer and Warren, J., 1933, 1300) had a capacity of 203 μμ F. with air as dielectric, and a calibration correction of only 0·18 μμ F. (Sugden, *loc. cit.*). The electronic polarisations were calculated from $[R_L]_D$ 67·85 for azobenzene (Duval, *Compt. rend.*, 1911, **153**, 874) and Eisenlohr's figures (*Z. physikal. Chem.*, 1895, **16**, 218), except for *p*-methoxyazobenzene, for which the averages of Bergmann and Weizmann's measurements (*loc. cit.*) were employed.

Solutions in benzene.

Phenyl benzoate, m.p. 71°.

f_2.	$\epsilon^{30°}$.	$d_{4°}^{30°}$.	$P_{1,2}$.	P_2.
0	2·2621	0·86836	26·619	
0·003734	2·2826	0·87025	27·018	133·4
0·007993	2·3040	0·87260	27·436	128·9
0·010940	2·3203	0·87417	27·748	129·8
0·014903	2·3438	0·87619	28·193	132·3

P_2 (mean), 131·1; P_E (calc.), 55·7; $P_2 - P_E$, 75·4.

p-Benzoyloxyazobenzene, m.p. 138°.

f_2.	$\epsilon^{30°}$.	$d_{4°}^{30°}$.	$P_{1,2}$.	P_2.
0·003691	2·2867	0·87177	27·162	174·3
0·007246	2·3105	0·87496	27·688	174·2
0·007606	2·3137	0·87538	27·750	175·1
0·012855	2·3474	0·87991	28·510	173·7

P_2 (mean), 174·3; P_E (calc.), 97·8; $P_2 - P_E$, 76·5.

	$\mu \times 10^{18}$.		$\mu \times 10^{18}$.
Phenol	1·70 (*b*), 1·61 (*c*)	*p*-Hydroxyazobenzene	1·62, 1·62 (*a*)
Anisole	1·2 (*d*)	*p*-Methoxyazobenzene	1·3, 1·29 (*a*)
Phenyl benzoate	1·92	*p*-Benzoyloxyazobenzene	1·93

(*a*) Bergmann and Weizmann (*loc. cit.*). (*b*) Smyth and Morgan (*J. Amer. Chem. Soc.*, 1927, **49**, 1030); Williams (*Physikal. Z.*, 1928, **29**, 174). (*c*) Donle and Gehrckens (*Z. physikal. Chem.*, 1922, *B*, **18**, 316). (*d*) Donle and Volkert (*ibid.*, 1930, *B*, **8**, 60); Hojendahl ("Studies in Dipole Moments," Thesis, Copenhagen, 1928; *Physikal. Z.*, 1929, **30**, 391); Estermann (*Z. physikal. Chem.*, 1928, *B*, **1**, 134).

EGYPTIAN UNIVERSITY, ABBASSIA, CAIRO. [*Received, September 8th,* 1937.]

The Cyclisation of 2-(β-1′-*Naphthylethyl*)-Δ²-cyclo*pentenone.* By STANLEY H. HARPER.

COHEN and COOK (J., 1935, 1570) were unable to cyclise 2-(β-1′-naphthylethyl)-Δ²-*cyclo*-pentenone by aluminium chloride in either benzene or nitrobenzene to 3′-keto-1 : 2 : 3 : 4-tetrahydro-1 : 2-*cyclo*pentenophenanthrene. It was thought that the use of phosphoric oxide might lead to the required ketone. The product isolated, however, was 1 : 2-*cyclo*pentenophenanthrene. The unsaturated ketone (6·3 g.) was heated with phosphoric oxide (13 g.) at 130° for 30 mins., considerable resinification occurring. The product was decomposed with ice and sodium hydroxide, and extracted with ether. After removal of the solvent, the residue gave on vacuum distillation 0·54 g. of crystalline material, which recrystallised from aqueous acetone or ethyl alcohol in clusters of shining plates, m. p. 134°, not depressed on admixture with an authentic specimen of 1 : 2-*cyclo*pentenophenanthrene (Kon, J., 1933, 1081; Harper, Kon, and Ruzicka, J., 1934, 124) (Found: C, 93·4; H, 6·5. Calc. for $C_{17}H_{14}$: C, 93·6; H, 6·4%). The identity was further confirmed by comparison of the picrate and the trinitrobenzene derivative. The unsaturated ketone was recovered unchanged from a similar experiment using syrupy phosphoric acid at 130° for 5 hrs.

The author thanks Asst. Prof. G. A. R. Kon for his interest in this work.—IMPERIAL COLLEGE OF SCIENCE, LONDON, S.W.7. [*Received, October 11th*, 1937.]

The Cyclisation of 2-(β-1'-*Naphthylethyl*)-Δ^2-cyclo*pentenone*. By STANLEY H. HARPER.

COHEN and COOK (J., 1935, 1570) were unable to cyclise 2-(β-1'-naphthylethyl)-Δ^2-*cyclo*pentenone by aluminium chloride in either benzene or nitrobenzene to 3'-keto-1 : 2 : 3 : 4-tetrahydro-1 : 2-*cyclo*pentenophenanthrene. It was thought that the use of phosphoric oxide might lead to the required ketone. The product isolated, however, was 1 : 2-*cyclo*pentenophenanthrene. The unsaturated ketone (6·3 g.) was heated with phosphoric oxide (13 g.) at 130° for 30 mins., considerable resinification occurring. The product was decomposed with ice and sodium hydroxide, and extracted with ether. After removal of the solvent, the residue gave on vacuum distillation 0·54 g. of crystalline material, which recrystallised from aqueous acetone or ethyl alcohol in clusters of shining plates, m. p. 134°, not depressed on admixture with an authentic specimen of 1 : 2-*cyclo*pentenophenanthrene (Kon, J., 1933, 1081; Harper, Kon, and Ruzicka, J., 1934, 124) (Found: C, 93·4; H, 6·5. Calc. for $C_{17}H_{14}$: C, 93·6; H, 6·4%). The identity was further confirmed by comparison of the picrate and the trinitrobenzene derivative. The unsaturated ketone was recovered unchanged from a similar experiment using syrupy phosphoric acid at 130° for 5 hrs.

The author thanks Asst. Prof. G. A. R. Kon for his interest in this work.—IMPERIAL COLLEGE OF SCIENCE, LONDON, S.W.7. [*Received, October 11th, 1937.*]

393. *Studies in the Naphthalene Series. Part I. Preparation of Polyhydroxy-derivatives of Naphthalene.*

By S. N. CHAKRAVARTI and V. PASUPATI.

1 : 2 : 6- and 1 : 2 : 7-Trihydroxy- and 1 : 2 : 5 : 6- and 1 : 2 : 7 : 8-tetrahydroxynaphthalene could not be prepared from the corresponding amino- or bromo-compounds. The two *trihydroxynaphthalenes* were obtained from 2 : 6- and 2 : 7-dihydroxynaphthalene by the sequence of changes: nitroso-compound, amino-compound, hydroxy-quinone, trihydroxynaphthalene; and various derivatives were prepared.

IN attempts to prepare tri- and tetra-hydroxynaphthalenes containing respectively one and two catechol nuclei, 2 : 6-dimethoxynaphthalene (Chakravarti, *J. Indian Chem. Soc.*, 1933, **10**, 694) was converted into the *mono*- and the *di-nitro*-compound and these were reduced to the corresponding amino-compounds: similar reactions were carried out with 2 : 7-dimethoxynaphthalene. None of the four amino-compounds, however, could be converted into the corresponding hydroxy-compound through the diazonium salt.

Halogen atoms in the 1 : 5-positions in naphthalene are reactive and readily form Grignard reagents (Salkind, *Ber.*, 1934, **67**, 1031). It was found, however, that although 1-bromo-2-methoxynaphthalene could be converted into 2-methoxy-1-naphthol in very poor yield through the Grignard compound, the conversion of 1 : 5-*dibromo*-2 : 6-*dimethoxynaphthalene* into 1 : 5-dihydroxy-2 : 6-dimethoxynaphthalene could not be brought about. Attempts to replace the bromine atoms directly by hydroxyl by means of aqueous or alcoholic potash, or by fusion with caustic potash, did not yield encouraging results.

Finally, 2 : 7-dihydroxynaphthalene was converted into its monomethyl ether; this was nitrosated, the nitroso-compound reduced to the corresponding amino-compound, and the hydrochloride of the base oxidised to 7-*methoxy*-1 : 2-*naphthaquinone*, which was readily reduced to 1 : 2-*dihydroxy*-7-*methoxynaphthalene* by sulphurous acid. 1 : 2 : 7-*Trihydroxynaphthalene* was even more readily obtained from 2 : 7-dihydroxynaphthalene by a similar series of reactions. Both compounds on methylation with methyl iodide and anhydrous potassium carbonate in dry acetone, gave the same trimethoxynaphthalene, characterised by its *picrate*, m. p. 115°.

The above method also produced 1 : 2 : 6-*trihydroxynaphthalene* from 2 : 6-dihydroxynaphthalene, but it could not be applied to 1 : 2 : 7-trihydroxynaphthalene, because this compound, on attempted nitrosation or nitration, was oxidised to the hydroxy-quinone. With the object, therefore, of preparing 1 : 2 : 7 : 8-tetrahydroxynaphthalene, 8-*nitro*-7-*hydroxy*-1 : 2-*naphthaquinone*, obtained by the nitration of 7-hydroxy-1 : 2-naphtha-

quinone, was reduced (1) to 8-amino-1 : 2 : 7-trihydroxynaphthalene by means of stannous chloride and hydrochloric acid, and (2) to 8-*nitro*-1 : 2 : 7-*trihydroxynaphthalene* by means of sulphurous acid; the latter compound was methylated, and the 8-*nitro*-1 : 2 : 7-*trimethoxynaphthalene* reduced to 8-amino-1 : 2 : 7-trimethoxynaphthalene. Neither amino-compound, however, could be oxidised to a naphthaquinone, and their amino-group could not be replaced by hydroxyl. The latter amino-compound was diazotisable and 8-*iodo*-1 : 2 : 7-*trimethoxynaphthalene* was readily prepared from it in the usual way.

EXPERIMENTAL.

1-*Nitro- and* 1 : 5-*Dinitro*-2 : 6-*dimethoxynaphthalene*.—(1) 2 : 6-Dimethoxynaphthalene (8 g.) in glacial acetic acid was treated with a mixture of nitric acid (9 g.; *d* 1·42) and glacial acetic acid (9 g.) at room temperature and after ½ hour the product was poured into ice-cold water. 1-*Nitro*-2 : 6-*dimethoxynaphthalene* crystallised from benzene in orange needles, m.p. 189° (Found : C, 61·6; H, 4·9; N, 6·1. $C_{12}H_{11}O_4N$ requires C, 61·8; H, 4·7; N, 6·0%).

(2) 2 : 6-Dimethoxynaphthalene (10 g.) in glacial acetic acid (150 c.c.) was similarly treated with a mixture of nitric acid (80 g.; *d* 1·42) and glacial acetic acid (80 g.), a mixture of sulphuric acid (20 g.) and glacial acetic acid (20 g.) being added before the ½ hour's standing. 1 : 5-*Dinitro*-2 : 6-*dimethoxynaphthalene* crystallised from pyridine in golden-yellow needles, m. p. 265° (Found : N, 10·1. $C_{12}H_{10}O_6N_2$ requires N, 10%); yield, almost quantitative.

1-*Amino- and* 1 : 5-*Diamino*-2 : 6-*dimethoxynaphthalene*.—(1) The mononitro-compound (5 g.) was warmed on the water-bath with stannous chloride (16 g.) in anhydrous alcohol (40 c.c.) saturated with dry hydrogen chloride. After ½ hour, on cooling, the *hydrochloride* of 1-amino-2 : 6-dimethoxynaphthalene separated; it crystallised from water in silky needles, m. p. 270° (decomp.) (Found : N, 5·9. $C_{12}H_{13}O_2N$,HCl requires N, 5·8%).

(2) The dinitro-compound (5 g.) was similarly treated (stannous chloride, 32 g.; anhydrous alcohol, 80 c.c.) for 1 hour with vigorous shaking. The hydrochloride of the base was collected after ½ hour, washed with dilute hydrochloric acid, and recrystallised from water, forming silky needles, m. p. 265° (decomp.). When its aqueous solution was basified, the *diamine* was precipitated; it crystallised from benzene in brown plates, m. p. 192° (Found : C, 66·1; H, 6·6; N, 12·9. $C_{12}H_{14}O_2N_2$ requires C, 66·0; H, 6·4; N, 12·8%).

2 : 7-*Dihydroxynaphthalene*.—The sodium salt of naphthalene-2 : 7-disulphonic acid (80 g.) was mixed with caustic potash (240 g.) in a nickel crucible and heated carefully with vigorous stirring at 290° for ½ hour and at 290—300° for 10 minutes. The melt was allowed to cool, lixiviated with water (1·2 l.), and acidified with concentrated hydrochloric acid (0·5 l.); 2 : 7-dihydroxynaphthalene (25 g.) separated in white plates, m. p. 194° after recrystallisation from dilute alcohol.

2 : 7-Dimethoxynaphthalene, prepared under conditions similar to those used for the 2 : 6-isomer (Chakravarti, *loc. cit.*), crystallised from alcohol in white needles, m. p. 138°.

1-Nitro-2 : 7-dimethoxynaphthalene, m. p. 141° (crystallised from alcohol), and 1 : 8-dinitro-2 : 7-dimethoxynaphthalene, m. p. 286° (crystallised from pyridine), were prepared by Fischer's method (*J. pr. Chem.*, 1916, **94**, 35).

1-*Amino*-2 : 7-*dimethoxynaphthalene*.—The nitro-compound was reduced in the same way as 1-nitro-2 : 6-dimethoxynaphthalene; on cooling, a stannichloride separated. This was dissolved in water and decomposed with hydrogen sulphide, and the filtered solution basified; the 1-*amino*-2 : 7-*dimethoxynaphthalene* obtained crystallised from aqueous alcohol in long silky needles, m. p. 83° (Found : N, 6·9. $C_{12}H_{13}O_2N$ requires N, 6·9%).

1 : 8-*Diamino*-2 : 7-*dimethoxynaphthalene*, prepared in the same way as 1 : 5-diamino-2 : 6-dimethoxynaphthalene, crystallised from aqueous alcohol in brownish needles, m. p. 115° (Found : N, 13·0. $C_{12}H_{14}O_2N_2$ requires N, 12·8%).

2-*Methoxy*-1-*naphthyl Benzoate*.—1-Bromo-2-methoxynaphthalene (Underwood, *J. Amer. Chem. Soc.*, 1930, **52**, 4090) (50 g.) was dissolved in dry ether (150 c.c.), magnesium turnings (6 g.) added, followed by bromine (0·5 c.c.) to start the reaction, and the whole was heated under reflux for 18 hours with vigorous shaking. Dry oxygen was slowly passed for 3 hours through the cold Grignard solution, which warmed perceptibly. The product was decomposed with dilute hydrochloric acid and extracted thrice with ether, and the extract shaken with 1% sodium hydroxide solution, which was then acidified and extracted with ether (five times). These extracts on evaporation left a residue, which was benzoylated in the usual manner. A benzene extract of the product was washed several times with 10% sodium hydroxide solution and with water, dried (sodium sulphate), and concentrated to a small volume, and sufficient

light petroleum added to produce a turbidity. On scratching and keeping for several hours, a substance (? dinaphthyl derivative), m. p. above 300°, separated; the mother-liquor, on further concentration and keeping, deposited 2-*methoxy*-1-*naphthyl benzoate* in cubic crystals, m. p. 110° after recrystallisation from benzene–light petroleum (Found: C, 77·5; H, 5·1. $C_{18}H_{14}O_3$ requires C, 77·7; H, 5·0%).

1 : 5-*Dibromo*-2 : 6-*dimethoxynaphthalene*.—2 : 6-Dimethoxynaphthalene (5 g.) in glacial acetic acid (150 c.c.) was brominated (bromine, 8·6 g., in glacial acetic acid, 16 c.c.) and after 1 hour the mixture was poured into water. The precipitated *dibromo*-compound was very sparingly soluble in all the usual organic solvents, but crystallised from nitrobenzene in colourless leaflets, m. p. 257° (Found: C, 41·3; H, 2·7. $C_{12}H_{10}O_2Br_2$ requires C, 41·6; H, 2·9%).

1 : 5-*Dibromo*-2 : 6-*dihydroxynaphthalene* separated when bromine (4 g.) in glacial acetic acid (8 c.c.) was gradually added to 2 : 6-dihydroxynaphthalene (2 g.) in glacial acetic acid (60 c.c.); recrystallised from alcohol, it formed needles, m. p. 223° (Found: C, 37·4; H, 1·6; Br, 49·8. $C_{10}H_6O_2Br_2$ requires C, 37·7; H, 1·9; Br, 50·2%). Methylation with methyl sulphate and alkali in methyl-alcoholic solution gave the preceding dimethoxy-compound, m. p. 257°.

7-*Methoxy*-1 : 2-*naphthaquinone*.—To a suspension of the hydrochloride [long needles, m. p. 257° (decomp.)] of 1-amino-7-methoxy-2-naphthol (10 g.) in 5% sulphuric acid (100 c.c.) below 0°, a cold solution of potassium dichromate (5 g.) in water (35 c.c.) was gradually added. The *quinone* was collected, washed with cold water, air-dried, and crystallised from benzene, separating in orange-yellow needles, m. p. 183° (Found: C, 70·0; H, 4·3. $C_{11}H_8O_3$ requires C, 70·2; H, 4·2%).

1 : 2-*Dihydroxy*-7-*methoxynaphthalene*.—A solution of the quinone (2 g.) in alcohol (50 c.c.) was warmed while sulphur dioxide was passed in. Part of the alcohol was then removed, and the residue diluted with water and extracted with ether. The extract was dried (sodium sulphate), and solvent removed. The residue solidified when scratched with a little benzene–light petroleum and on recrystallisation from ligroin the *dihydroxy*-compound separated in colourless leaflets, which turned brown in air; m. p. 127° (Found: C, 69·4; H, 5·5. $C_{11}H_{10}O_3$ requires C, 69·5; H, 5·3%). The *picrate* formed needles, m. p. 156°, from alcohol (Found: N, 10·3. $C_{11}H_{10}O_3,C_6H_3O_7N_3$ requires N, 10·0%). The *diacetoxy*-compound, obtained by heating with acetic anhydride and sodium acetate for 2 hours on the steam-bath, crystallised from dilute alcohol in long needles, m. p. 122° (Found: C, 65·7; H, 5·2. $C_{15}H_{14}O_5$ requires C, 65·7; H, 5·1%).

7-Hydroxy-1 : 2-naphthaquinone was prepared by Dimroth and Kerkovius's method (*Annalen*, 1913, **399**, 42; see also *Ber.*, 1889, **22**, 522; 1897, **30**, 1123). It can be obtained in 95% yields and in an excellent state of purity if the amine hydrochloride is freshly prepared and recrystallised from hydrochloric acid containing a small quantity of stannous chloride, which serves as an anti-oxidant (compare Fieser, *J. Amer. Chem. Soc.*, 1935, **57**, 493).

6-Hydroxy-1 : 2-naphthaquinone, prepared by the series of reactions outlined on p. 1859, starting from 2 : 6-dihydroxynaphthalene, crystallised from acetone in orange-yellow needles, m. p. 165°.

1 : 2 : 7-*Trihydroxynaphthalene*.—Sulphur dioxide was passed through a suspension in warm water of 7-hydroxy-1 : 2-naphthaquinone (10 g.), which gradually dissolved. An ethereal extract of the filtered solution was dried and evaporated, and the residue of 1 : 2 : 7-*trihydroxynaphthalene* crystallised from ligroin or xylene; it formed microscopic cubic crystals, m. p. 197° (Found: C, 68·3; H, 4·6. $C_{10}H_8O_3$ requires C, 68·1; H, 4·5%).

1 : 2 : 6-*Trihydroxynaphthalene*, similarly prepared from 6-hydroxy-1 : 2-naphthaquinone, crystallised from ligroin in small needles, m. p. 188° (Found: C, 68·3; H, 4·7%).

1 : 2 : 7-*Trimethoxynaphthalene*.—1 : 2-Dihydroxy-7-methoxy- or 1 : 2 : 7-trihydroxy-naphthalene was refluxed in dry acetone with an excess of methyl iodide and potassium carbonate for 8 hours. Most of the acetone was then removed, and the residue diluted with water and extracted with ether. The extract was washed with aqueous sodium hydroxide, dried (sodium sulphate), and evaporated, leaving an oily residue of 1 : 2 : 7-trimethoxynaphthalene, the *picrate* of which crystallised from dilute alcohol in red needles, m. p. 115° (Found: C, 51·3; H, 3·9. $C_{13}H_{14}O_3,C_6H_3O_7N_3$ requires C, 51·0; H, 3·8%).

1 : 2 : 6-*Trimethoxynaphthalene*, prepared by the same method, crystallised from methyl alcohol–light petroleum in small cubes, m. p. 55° (Found: C, 71·8; H, 6·3. $C_{13}H_{14}O_3$ requires C, 71·5; H, 6·4%). The *picrate* formed red needles, m. p. 98°, from aqueous alcohol (Found: C, 51·2; H, 3·7%).

1 : 2 : 7- and 1 : 2 : 6-*Triacetoxynaphthalene*, obtained by heating the trihydroxy-compounds with acetic anhydride and sodium acetate on the water-bath for ½ hour, crystallised from

toluene in colourless cubes, m. p. 181—182° (Found : C, 63·6; H, 4·8%) and 262° (Found : C, 63·7; H, 4·8. $C_{16}H_{14}O_6$ requires C, 63·6; H, 4·6%), respectively.

8-*Nitro*-7-*hydroxy*-1 : 2-*naphthaquinone*.—Nitric acid (10 c.c.; *d* 1·42) was added all at once with vigorous stirring to a suspension of 7-hydroxy-1 : 2-naphthaquinone (20 g.) in glacial acetic acid (160 c.c.) and the mixture was stirred for an hour, the temperature throughout being kept below 35°. The product was poured into water, and the precipitate of 8-*nitro*-7-*hydroxy*-1 : 2-*naphthaquinone* crystallised from glacial acetic acid, forming clusters of red needles, m. p. 210° (decomp.) (Found: C, 54·8; H, 2·3; N, 6·6. $C_{10}H_5O_5N$ requires C, 54·8; H, 2·3; N, 6·4%).

5-*Nitro*-6-*hydroxy*-1 : 2-*naphthaquinone*, similarly obtained from 6-hydroxy-1 : 2-naphthaquinone, crystallised from alcohol and glacial acetic acid in needles, m. p. 205° (Found: N, 6·5%).

8-*Nitro*-1 : 2 : 7-*trihydroxynaphthalene*.—Sulphur dioxide was passed through a suspension of 8-nitro-7-hydroxy-1 : 2-naphthaquinone (5 g.) in water (100 c.c.) at 60°; the nitro-compound dissolved and then 8-*nitro*-1 : 2 : 7-*trihydroxynaphthalene* was almost immediately precipitated. It crystallised from dilute alcohol in red needles, m. p. 220° (Found : N, 6·1. $C_{10}H_7O_5N$ requires N, 6·3%).

8-*Nitro*-1 : 2 : 7-*trimethoxynaphthalene*, prepared from the preceding compound by the method described for 1 : 2 : 7-trimethoxynaphthalene, crystallised from alcohol in golden-yellow needles, m. p. 98° (Found : N, 5·5. $C_{13}H_{13}O_5N$ requires N, 5·3%).

5-*Nitro*-1 : 2 : 6-*trimethoxynaphthalene*, obtained from 5-nitro-6-hydroxy-1 : 2-naphthaquinone by a similar series of reactions, crystallised from alcohol in golden-yellow needles, m. p. 93° (Found : N, 5·5%).

8-*Amino*-1 : 2 : 7-*trihydroxynaphthalene*.—8-Nitro-7-hydroxy-1 : 2-naphthaquinone (1 g.) was warmed on the water-bath with stannous chloride (6 g.) and hydrochloric acid (5 c.c.) until it dissolved. The solution was then saturated with dry hydrogen chloride and left overnight; the *amine hydrochloride* separated in long clusters of needles, m. p. 270—275° (decomp.) (Found : N, 6·2. $C_{10}H_9O_3N$,HCl requires N, 6·2%).

8-*Amino*-1 : 2 : 7-*trimethoxynaphthalene*.—8-Nitro-1 : 2 : 7-trimethoxynaphthalene (4 g.) was warmed on the water-bath with a slight excess of stannous chloride and fuming hydrochloric acid; reduction was complete in 10 minutes and, on cooling, long colourless needles of the *amine hydrochloride* separated, m. p. 255° (decomp.) after recrystallisation from concentrated hydrochloric acid (Found : N, 5·4. $C_{13}H_{15}O_3N$,HCl requires N, 5·2%).

8-*Iodo*-1 : 2 : 7-*trimethoxynaphthalene*.—8-Amino-1 : 2 : 7-trimethoxynaphthalene (0·63 g.) was stirred in 10% sulphuric acid (5 c.c.) cooled in a freezing mixture, and sodium nitrite (0·2 g. in 1 c.c. of water) gradually added. When the reaction was over, potassium iodide (0·6 g. in 1 c.c. of water) was gradually added with stirring and after some time the mixture was heated on the steam-bath for 1 hour. The *product* was extracted with ether, dried (sodium sulphate), and recovered as an oily residue, which separated from light petroleum (b. p. 80—90°) in rhombic crystals, m. p. 72° (Found : C, 45·2; H, 3·6. $C_{13}H_{13}O_3I$ requires C, 45·4; H, 3·8%).

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394. *Rottlerin. Part I.*

By Kartar Singh Narang, Jnanendra Nath Ray, and Bharpur Singh Roy.

Determinations of the molecular weights of various derivatives indicate that rottlerin has the formula $C_{27}H_{26}O_7$. It forms a tetrahydro-derivative, a tetra-acetyl derivative and a *tetramethyl* ether. This ether is oxidised by alkaline hydrogen peroxide, a *substance* $C_{31}H_{36}O_8$ being formed which on catalytic reduction is converted into *tetrahydrorottlerin tetramethyl ether*, indicating that an oxygen atom attaches itself to a double bond during oxidation.

Rottlerin tetramethyl ether gives a *substance* $C_{19}H_{21}O_6N$ when treated with nitrous acid at 40°.

Rottlerin has often been investigated (for references, see McGookin, Reed, and Robertson, this vol., p. 748) and the formula in vogue at present is $C_{33}H_{30}O_9$, which was advocated by Perkin (J., 1895, 67, 230), although Robertson admitted the possibility of a C_{34} formula.

Telle (*Arch. Pharm.*, 1906, **244**, 441) confirmed the empirical formula $C_{11}H_{10}O_3$, but found 496 for the molecular weight in naphthalene. Dutt (*J.*, 1925, **127**, 2044) obtained the values 585, 615, and 598 in boiling toluene and 675 by the silver salt method. Since, however, rottlerin is a polyhydric phenol, the evidence of molecular weight cannot be accepted without reserve. We have isolated a *tetramethyl* ether which, unlike the ether described by Dutt (which we have been unable to obtain), does not form an acetyl derivative; therefore its molecular weight, which agrees with the formula $C_{27}H_{26}O_7$ for rottlerin, is unlikely to be influenced by association or dissociation.

Genuine kamala powder was procured from Raja Sir Daya Kishen Kaul and Sons, Lahore, and rottlerin isolated essentially as prescribed by Dutt; its m. p. was 209°. McGookin, Reed, and Robertson (*loc. cit.*) found that crystallisation of rottlerin from toluene as recommended by Dutt appeared to cause slight resinification. We have noticed no signs of resinification provided the substance is not heated too long during dissolution. Crystallisation from ethyl acetate did not change the m. p. and the crystals were homogeneous under the microscope. Tetrahydrorottlerin is formed in quantitative yield from rottlerin and we believe that degradation of the molecule does not take place during reduction. Robertson *et al.* acetylated rottlerin at room temperature for 5 days and isolated an acetyl derivative, m. p. 213°, which was also formed in a much shorter time by boiling rottlerin with acetic anhydride; we confirm their statement that in no circumstances is the acetyl derivative described by Dutt formed. Analysis of the acetyl derivative gives results in better agreement with the C_{27} than the C_{33} formula for rottlerin: the difference in the two carbon values is 1%. The molecular weight of the acetyl derivative of tetrahydrorottlerin also agrees with the C_{27} formula.

The methylation of rottlerin by all the usual methods gives uncrystallisable mixtures.

When rottlerin tetramethyl ether (the methoxyl content of which completely militates against a C_{33} structure for rottlerin) is oxidised by alkaline hydrogen peroxide, it is quantitatively converted into a *substance* $C_{31}H_{36}O_8$, m. p. 128° (decomp.), which on catalytic reduction is converted into *tetrahydrorottlerin tetramethyl ether*. Rottlerin tetramethyl ether, on treatment with sodium nitrite and acetic acid, gives a *substance* $C_{19}H_{21}O_6N$(?), which is catalytically reducible to a *dihydro*-derivative.

The hydrolysis of tetrahydrorottlerin with hydrochloric acid in alcohol furnished a substance $C_{20}H_{22}O_4$, m. p. 171°, which we think may be identical with the similar product isolated by Robertson *et al.* from tetrahydrorottlerin by hydrolysis with sodium hydroxide (*loc. cit.*, p. 753).

Experimental.

Rottlerin, isolated essentially as described by Dutt, washed with alcohol, and crystallised thrice from toluene (without prolonged heating), had m. p. 209° (Found: C, 69·83, 69·99; H, 5·63, 5·33. Calc. for $C_{27}H_{26}O_7$: C, 70·13; H, 5·63%. Calc. for $C_{33}H_{30}O_9$: C, 69·47; H, 5·26%).

A colouring matter was isolated from the benzene filtrate and obtained in pale yellow needles, m. p. 181° (acetyl derivative, m. p. 200°; methyl ether, m. p. 105°). It has not been described by other workers and its examination is reserved for the time being.

The acetyl derivative of rottlerin was formed when rottlerin (1·0 g.), acetic anhydride (5 c.c.), and pyridine (2 drops) were refluxed for 1½ hours. It crystallised from ethyl acetate (charcoal) in prisms and had m. p. 214° after recrystallisation from ethyl acetate or alcohol [Found: C, 66·8, 66·72; H, 5·3, 5·6; CH_3·CO, 27·4. Calc. for $C_{27}H_{22}O_3(O{\cdot}CO{\cdot}CH_3)_4$: C, 66·6; H, 5·4; CH_3·CO, 27·4%. Calc. for $C_{33}H_{26}O_5(O{\cdot}CO{\cdot}CH_3)_4$: C, 65·7; H, 5·1; CH_3·CO, 31·4%. Often a high value for acetyl is obtained owing to decomposition of sulphuric acid by the substance, unless precautions are taken to prevent it].

Tetrahydrorottlerin.—Rottlerin (1 g.), dissolved in purified ethyl acetate (40 c.c.) and alcohol (6 c.c.), was completely reduced in 1½ hours in presence of 3 c.c. of 1% palladium chloride solution. The product, crystallised successively from benzene, toluene, and ethyl acetate, had m. p. 212°. In an experiment in which 3 g. of rottlerin were reduced, 370 c.c. of hydrogen were absorbed at 18°/748 mm., indicating the absorption of approximately 4H per molecule [Found: C, 69·30, 69·41, 69·59; H, 6·30, 6·57, 6·49; *M* (micro-Rast), 476. Calc. for $C_{27}H_{30}O_7$: C, 69·51; H, 6·44%; *M*, 466. Calc. for $C_{33}H_{34}O_9$: C, 68·99; H, 5·92%; *M*, 574].

Tetra-acetyl Tetrahydrorottlerin.—Tetrahydrorottlerin (3·5 g.), acetic anhydride (15 c.c.), and pyridine (1 c.c.) were refluxed together for 1½ hours and the mixture was cooled and poured into water (400 c.c.). The product (4·7 g.), crystallised from ethyl acetate and then from alcohol, had m. p. 178°. The same substance, m. p. and mixed m. p. 178°, was obtained when tetra-acetyl rottlerin (m. p. 214°) (0·8 g.) was dissolved in ethyl acetate (100 c.c.) and alcohol (20 c.c.) and reduced in presence of 10 c.c. of 1% palladium chloride solution. Robertson *et al.* give m. p. 188° [Found: C, 65·92, 65·92, 65·76; H, 5·69, 5·75, 6·19; *M* (micro-Rast), 642; *M* (cryoscopic in benzene), 630, 641. Calc. for $C_{27}H_{22}O_3(O{\cdot}CO{\cdot}CH_3)_4$: C, 66·24; H, 5·99%; *M*, 634].

Rottlerin Tetramethyl Ether.—A mixture of rottlerin (2 g.), dry potassium bicarbonate (16 g.), methyl sulphate (8 c.c.), and purified acetone (50 c.c.) was refluxed on the steam-bath for 4 hours. Anhydrous potassium carbonate (8 g.) was now introduced, and the heating continued. After 45 minutes, when the solution had become pale yellow, the acetone was distilled off, and the residue diluted with water (150 c.c.) and left for 12 hours. The pale yellow solid was collected and crystallised from 90% alcohol. The *tetramethyl* ether is very soluble in acetone, glacial acetic acid, benzene, and ethyl acetate and is crystallisable from light petroleum; m. p. 144° [Found: C, 71·71; H, 6·65; OMe, 24·13; *M* (micro-Rast), 524, 562. $C_{27}H_{22}O_3(OMe)_4$ requires C, 71·81; H, 6·56; OMe, 23·94%; *M*, 518. $C_{33}H_{24}O_3(OMe)_6$ requires C, 71·56; H, 6·42; OMe, 28·4%; *M*, 654].

Tetrahydrorottlerin Tetramethyl Ether.—Tetrahydrorottlerin (2·5 g.), pure methyl sulphate (10 c.c.), acetone (100 c.c.), and potassium carbonate (20 g.) were refluxed together for 4 hours. As soon as the bright yellow colour of the solution changed to pale yellow, acetone was distilled off and water (400 c.c.) was added to the residue. After 16 hours, the solid was collected, washed with water, and crystallised from 90% alcohol, forming colourless plates, m. p. 108°, readily soluble in acetone, ethyl acetate, and benzene and moderately soluble in hot ethyl and methyl alcohol [Found: C, 71·27, 71·32; H, 7·29, 7·41. $C_{27}H_{26}O_3(OMe)_4$ requires C, 71·26; H, 7·28%]. When rottlerin tetramethyl ether (1 g.) was reduced in ethyl acetate (40 c.c.) and alcohol (10 c.c.) in presence of 5 c.c. of 1% palladium chloride solution, the same *tetrahydrorottlerin tetramethyl ether* was formed (m. p. and mixed m. p.).

Action of Hydrochloric Acid in Alcohol on Tetrahydrorottlerin.—Tetrahydrorottlerin (2 g.), alcohol (60 c.c.), hydrochloric acid (*d* 1·16, 6 c.c.), and water (4 c.c.) were refluxed together for 32 hours. The liquid was filtered hot; on cooling, it deposited a brownish solid, which was collected and triturated with ether. This removed a crimson-red powder, m. p. 274—278°, which was soluble in sodium bicarbonate solution but could not be satisfactorily crystallised. The ether-insoluble portion crystallised from ethyl acetate in brownish plates, m. p. 171° (Found: C, 73·5, 73·7; H, 6·9, 7·1. Calc. for $C_{20}H_{23}O_4$: C, 73·6; H, 6·75%).

Oxidation of Rottlerin Tetramethyl Ether with Alkaline Hydrogen Peroxide.—The ether (1·0 g.) was dissolved in 8% sodium hydroxide solution (20 c.c.) and heated to 40°, and 30% hydrogen peroxide (8 c.c.) and 8% sodium hydroxide solution (5 c.c.) added alternately during ½ hour. After 1 hour the solution deposited a colourless crystalline *substance* (0·96 g.), which, recrystallised from not too hot methyl or ethyl alcohol, formed plates, m. p. 127—128° with evolution of benzaldehyde (Found: C, 70·06, 69·87; H, 7·19, 7·27; OMe, 23·49. $C_{31}H_{36}O_8$ requires C, 69·4; H, 6·7; OMe, 23·13%).

Tetrahydrorottlerin tetramethyl ether was not affected under the conditions of the above experiment. The foregoing substance (0·05 g.), m. p. 128°, was dissolved in ethyl alcohol (60 c.c.) and reduced with palladium and hydrogen; tetrahydrorottlerin tetramethyl ether (m. p. and mixed m. p. 108°) was formed, indicating that an oxygen atom had been added to one of the double bonds. The foregoing oxide (0·5 g.) was dissolved in acetic acid (10 c.c.) and refluxed with N/2-sulphuric acid (4 c.c.) for 1 hour; benzaldehyde was isolated by steam-distillation and identified as the phenylhydrazone (m. p. and mixed m. p. 155°).

Action of Nitrous Acid on Rottlerin Tetramethyl Ether.—The ether (1·3 g.) was dissolved in acetic acid (15 c.c.) by gentle warming, and sodium nitrite (10 g.) added gradually to the cooled solution during ½ hour. The solution was then warmed at 80° for 10 minutes and diluted with water. The golden-yellow solid obtained was washed with water, dried, and triturated with ether (60 c.c.). The insoluble portion (0·9 g.) crystallised from toluene in pale yellow plates, m. p. 208—209° (decomp.) (Found: C, 63·66; H, 6·2; N, 4·2, 4·17. $C_{17}H_{19}O_5N$ requires C, 64·35; H, 5·99; N, 4·41%. $C_{19}H_{21}O_6N$ requires C, 63·51; H, 5·85; N, 3·89%). This *substance*, when boiled with dilute alkali solution, gave benzaldehyde.

The foregoing substance (1 g.), dissolved in ethyl acetate (30 c.c.) and alcohol (15 c.c.), was reduced in presence of 3 c.c. of 1% palladous chloride solution. The *product*, isolated by the

removal of the solvents in a vacuum, crystallised from alcohol in bunches of colourless needles, m. p. 162°. The same product was formed when the reduction was done with Adams's platinum oxide catalyst (Found: C, 63·44; H, 6·23; N, 3·85. $C_{19}H_{23}O_6N$ requires C, 63·2; H, 6·4; N, 3·8%).

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395. *Studies in the Light Absorption of Organic Compounds. Part VIII. Azo-compounds.*

By A. Burawoy.

It has been shown in previous communications of this series that there appear between 2000 and 8000 A. two different types of absorption band due to two different types of chromophore: (i) bands of very low intensity ($\epsilon < 2000$) due to multiple linkages (*R*-bands, *R*-chromophores); (ii) bands of high intensity ($\epsilon > 5000$) due to conjugated systems (*K*-bands, *K*-chromophores). These two types of absorption band also obey very different optical laws. In the present paper the absorption spectra of numerous azo-compounds are reported, with a view to testing the validity of the classification previously given. The previous results are confirmed.

The chemical problem of the light absorption (colour) of organic compounds consists primarily in establishing what groups or atoms (chromophores) are necessary for the presence of the electron (or electron system) responsible for the appearance of an absorption band between 2000 and 8000 A. Previous investigations (Burawoy, *Ber.*, 1930, **63**, 3155; 1931, **64**, 462, 1676; 1932, **65**, 941, 947; 1933, **66**, 228; *J. pr. Chem.*, 1932, **135**, 145) have shown that such bands are always due to two different types of chromophore, producing two different types of absorption band: (i) Unsaturated atoms of free radicals such as the methyl carbon atom of triarylmethyls, and all multiple linkages (being in a radical-like state) (*R*-chromophores, *R*-bands); (ii) conjugated systems, *i.e.*, all those represented by the general formula (I) (*K*-chromophores, *K*-bands)

$$\text{(I.)}\quad A{\cdot}[CH{:}CH]_n{\cdot}CH{:}B$$

$$(A = R, OR, SR, NR_2, \bar{O}, \bar{S}, \bar{N}R;\ B = CR_2, NR, O, S, \overset{+}{N}R_2, \overset{+}{O}R, \overset{+}{S}R.)$$

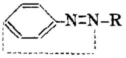
The changes of the position and intensity of these absorption bands due to changes of the chromophoric groups or their substituents, etc., have also been discussed. It has been shown that these two types of absorption band are not only distinguished by their

Compound.	*R*-Band, A. $\lambda_{max.}$	*R*-Band, A. $\epsilon_{max.}$	*K*-Band, A. $\lambda_{max.}$	*K*-Band, A. $\epsilon_{max.}$
Benzeneazomethane	4035	87	2595	7,800
* ,,	(none)		3340	9,900
Benzeneazotriphenylmethane	4205	180	2660	13,500
Azobenzene	4480	425	3130	20,000
* ,,	(none)		4225	28,800
Benzeneazodiphenyl	4505	900	3345	30,000
Benzeneazo-α-naphthalene	4630	1170	3700	14,000 ‡
p-Methoxyazobenzene	4400	750	3380	24,700
† ,,	4305	1050	3415	24,000
o- ,,	4550	676	3145	13,600
† ,,	4480	893	3165	14,000
m- ,,	4445	560	3125	22,000
p-Aminoazobenzene	(infl.)		3620	27,500
N-Benzeneazopiperidine	(none)		2895	16,000
Benzeneazo-α-naphthyl methyl ether	(infl.)		3920	17,800 §
Benzeneazo-β-naphthyl methyl ether	4690	1420	3720	8,100 ‖
Benzophenone	3380	110	—	—
Benzpinacolin	3330	220	—	—

* Solvent, sulphuric acid.
† Solvent, alcohol.
‡ Another band at 2600 A., ϵ = 12,000.
§ Another band at 2700 A., ϵ = 14,800.
‖ An inflexion at 2700 A., ϵ = 13,500.

very different intensities, but also follow different absorption laws. The results obtained represent a classification of the chromophoric groups and their laws which considers all known facts and can be systematically tested by the investigation of new examples. In the present paper the absorption spectra of numerous azo-compounds are reported, and serve as a further test of the validity of this classification. In the table are enumerated the absorption maxima and molecular extinction coefficients of the compounds in hexane solution (unless otherwise stated). The determinations were carried out with a Hilger E3 quartz spectrograph fitted with a Spekker photometer, a tungsten-steel high-tension spark being employed as the source of light.

According to Hantzsch and Lifschitz (*Ber.*, 1912, **45**, 3011), azomethane, NMe:NMe, in alcohol possesses a band at 3470 A. ($\varepsilon < 10$) distinguished by the very low intensity characteristic of all *R*-bands (cf. *Ber.*, 1930, **63**, 3155). There is no doubt that it is due to the azo-group. Replacement of a methyl by a phenyl group, as in benzeneazomethane, NPh:NMe, displaces this *R*-band to longer wave-lengths (4035 A., $\varepsilon = 87$), as is the case for the *R*-bands of all multiple linkages (*ibid.*, p. 3158). In addition, since benzeneazomethane contains a conjugated system indicated by the broken line in (II; R = Me), a new band appears at 2595 A. ($\varepsilon = 7800$) with the high intensity characteristic of all *K*-bands (*loc. cit.*) (Fig. 1).

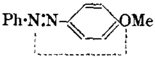


(II.)*

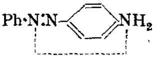
A comparison of the spectra of benzeneazomethane (II; R = Me), benzeneazotriphenylmethane (II; R = CPh_3), azobenzene (II; R = Ph), benzeneazodiphenyl (II; R = C_6H_4Ph), and benzeneazo-α-naphthalene (II; R = α-$C_{10}H_7$) (Fig. 1) shows that the *R*-band is displaced to longer wave-lengths in this order (cf. *Ber.*, 1930, **63**, 3155, for the effect of different hydrocarbon substituents on the *R*-bands of other multiple linkages).

The interpretation of the effect of the different hydrocarbons on the *K*-band of benzeneazomethane is rather difficult. Although the intensive bands appearing in the spectra of these substances are, undoubtedly, due to conjugated systems, yet in such substances as benzeneazo-α-naphthalene or -diphenyl no exact attribution of this band to one of the several conjugated systems present is possible. If we make the simplifying assumption that the absorbing conjugated system is in all cases the same as in benzeneazomethane (indicated in II), we see that the various groups R are substituents not only of the azo-*R*-chromophore but also of this chromophoric (conjugated) system. Consequently, they also displace the *K*-band in the same series to longer wave-lengths. However, it is possible that in the case of benzeneazo-α-naphthalene the chromophoric group will be represented by the system indicated in (V). Furthermore, this substance possesses a second intensive band at 2690 A. ($\varepsilon = 12,000$), probably identical with a band characteristic of naphthalene itself (fine structure with most intense bands at 2720 and 2750 A.).

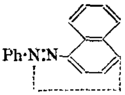
The effect of the amino- and the hydroxy-group is very remarkable. It has been shown (*loc. cit.*) that these groups displace a *K*-band considerably to longer wave-lengths



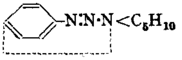
(III.)



(IV.)



(V.)



(VI.)

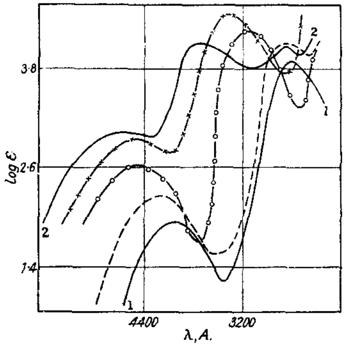
if they are on the end of the absorbing conjugated system (cf. I; A = OR,NR_2). In agreement with this, the *K*-band is displaced to longer wave-lengths in the series: azobenzene, *p*-methoxyazobenzene (III), *p*-aminoazobenzene (IV) (Fig. 2), benzeneazo-α-naphthalene (V), benzeneazo-α-naphthyl methyl ether (as III) (Fig. 3), and benzeneazomethane (II; R = Me), *N*-benzeneazopiperidine (VI) (Fig. 4).

On the other hand, in a branch of a conjugated system or as substituents of an

* The broken line only formally indicates the conjugated system.

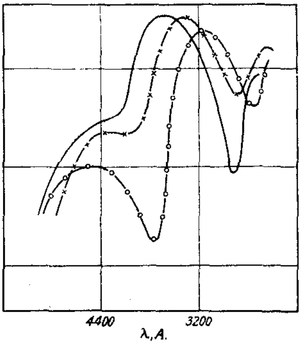
R-chromophore, these groups strongly displace the corresponding absorption band to shorter wave-lengths. This is illustrated by a comparison of the spectra of benzeneazomethane and -piperidine (Fig. 4). In the spectrum of the latter no *R*-band is detectable

FIG. 1.



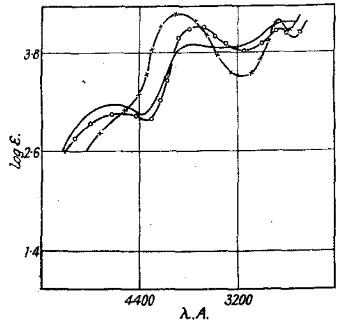
1———— *Benzeneazomethane.*
— — — *Benzeneazotriphenylmethane.*
—o—o— *Azobenzene.*
—x—x— *Azodiphenyl.*
2———— *Benzeneazo-α-naphthalene.*

FIG. 2.



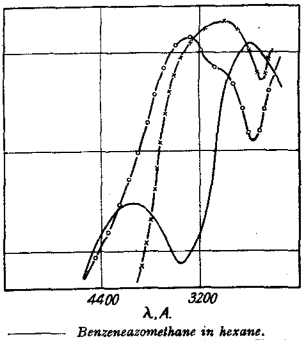
—o—o— *Azobenzene.*
—x—x— p-*Methoxyazobenzene.*
———— p-*Aminoazobenzene.*

FIG. 3.



———— *α-Benzeneazo-β-naphthyl methyl ether.*
—o—o— *Benzeneazo-α-naphthalene.*
—x—x— *Benzeneazo-α-naphthyl methyl ether.*

FIG. 4.



———— *Benzeneazomethane in hexane.*
—o—o— *Benzeneazomethane in conc.* H_2SO_4.
—x—x— N-*Benzeneazopiperidine in hexane.*

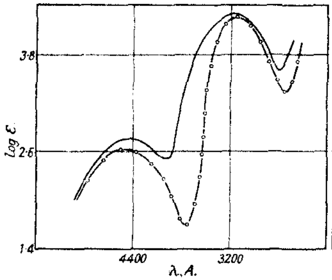
since, being strongly displaced to shorter wave-lengths, it is superposed by the intensive *K*-band present (contrast with the *K*-bands).

When indirectly connected with the chromophoric groups, *i.e.*, by an aromatic substituent, a hydroxyl or amino-group displaces the corresponding absorption band only slightly (in most cases to shorter wave-lengths). Thus, in contrast to the *K*-band, the

R-band of *p*-methoxyazobenzene absorbs at shorter wave-lengths than that of azobenzene (Fig. 2). Although the *R*-bands are only indicated as inflexions in the spectra of *p*-aminoazobenzene (IV) and benzeneazo-α-naphthyl methyl ether (as III), being partly superposed by the intensive *K*-bands, comparison with the spectra of azobenzene and benzeneazo-α-naphthalene, respectively, clearly indicates that this band has been displaced to shorter wave-lengths (Figs. 2 and 3).

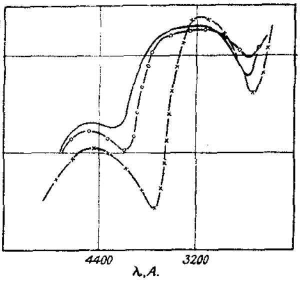
Furthermore, the methoxyl group in *m*-methoxyazobenzene, being only a substituent of both the *R*- and the *K*-chromophore, has no significant effect on the position of either

FIG. 5.



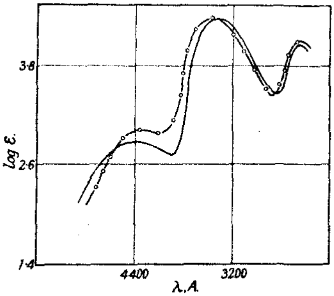
——— m-*Methoxyazobenzene.*
—o—o— *Azobenzene.*

FIG. 6.



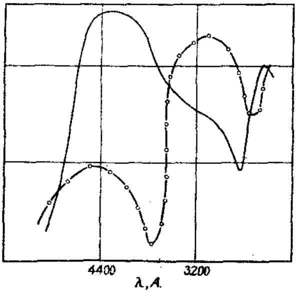
——— o-*Methoxyazobenzene in alcohol.*
—o—o— o-*Methoxyazobenzene in hexane.*
—x—x— *Azobenzene in hexane.*

FIG. 7.



——— p-*Methoxyazobenzene in hexane.*
—o—o— p-*Methoxyazobenzene in alcohol.*

FIG. 8.

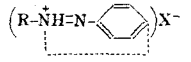


——— *Azobenzene in conc.* H_2SO_4.
—o—o— *Azobenzene in hexane.*

the *R*- or the *K*-band of azobenzene (Fig. 5). For the same reason, the introduction of a methoxyl group in the *o*-position has only a very slight effect on the maxima of both bands. A comparison of the spectra of azobenzene and benzeneazo-α-naphthalene with those of *o*-methoxyazobenzene and benzeneazo-β-naphthyl methyl ether shows that a slight shift of both bands, this time to longer wave-lengths, has taken place (Figs. 6 and 3). This effect is, however, not comparable with the strong displacement to longer wave-lengths by a methoxyl group on the end of an absorbing conjugated system, as is already shown in *p*-methoxyazobenzene and benzeneazo-α-naphthyl methyl ether.

The dependence of the absorption bands on the solvent is again very characteristic. It has been shown (*loc. cit.*) that the *R*-bands are always displaced to shorter, and the *K*-bands to longer, wave-lengths in approximately the increasing order of dielectric constant (dipole moment) of the solvent. This is now confirmed for the azo-*R*-chromophore by a comparison of the spectra of *o*- and *p*-methoxyazobenzene in hexane and in alcohol (Figs. 6 and 7). In alcohol, the *R*-band absorbs at shorter, the *K*-band at longer, wave-lengths. Similar effects have already been observed for the azo-*R*-band of benzeneazo-β- and -α-naphthyl methyl ethers (Burawoy and Markowitsch, *Annalen*, 1933, **503**, 180). It follows that the best separation of the *R*-band and the *K*-band can be expected in hexane, for which reason the determinations have been carried out in this solvent.

The influence of the addition of an acid molecule, *i.e.*, a hydrogen nucleus, to a chromophore on the *R*- and *K*-bands emphasises their different behaviour. Whereas the addition to the *R*-chromophore destroys the corresponding band, and consequently such bands do not appear in organic cations (cf. *Ber.*, 1931, **64**, 482), yet the addition to a conjugated system, *i.e.*, the replacement of the groups (N)C:O, (N)C:NR, (N)C:S by the groups (N)C:$\overset{+}{O}$R, (N)C:$\overset{+}{N}R_2$, (N)C:$\overset{+}{S}$R respectively (cf. I; B), displaces the corresponding *K*-bands strongly to longer wave-lengths. As shown in Figs. 8 and 4, the *R*-bands of azobenzene and benzeneazomethane disappear and the *K*-bands are strongly displaced to longer wave-lengths in the spectra of their salts (VII; R = Ph or Me) in concentrated sulphuric acid.



(VII.)

It has been found (*Ber.*, 1931, **64**, 762) that the intensity of the *R*-bands (independently of the displacement to shorter or longer wave-lengths) for a given series of substituents increases in the same order as the dissociation of ethanes and hydrazines into their radicals. This result is of some importance for the recognition of the radical-like structure of the *R*-chromophores (multiple linkages in their absorbing state) and is again confirmed. The intensity of the azo-*R*-band increases in the series Me < Ph < C_6H_4Ph < α-$C_{10}H_7$ and Ph < C_6H_4·OMe (*m*, *o*, *p*) (cf. table and figures).

The triphenylmethyl group shows a greater effect than a methyl group, but a smaller one than the phenyl group, although pentaphenylethyl is less associated than triphenylmethyl (Schlenk and Mark, *Ber.*, 1922, **55**, 285). However, the effect of this group on a nitrogen atom may differ from that on a carbon atom. This view is supported by the observation that the carbonyl *R*-band of benzpinacolin is, in fact, more intense (ε = 220) than the *R*-band of benzophenone (ε = 110) (cf. table; and Burawoy, *Ber.*, 1930, **63**, 3160). Incidentally, the author's previous statement that a triphenylmethyl substituent displaces an *R*-band more strongly to longer wave-lengths than a phenyl substituent is erroneous and is now corrected.

The author thanks Professor I. M. Heilbron, F.R.S., for the many facilities he has afforded him, and acknowledges with gratitude grants from the Society for the Protection of Science and Learning, London, Imperial Chemical Industries Ltd. (Dyestuffs Group), and the Research Fund Committee of the Chemical Society.

The University of Manchester. [*Received, September 24th*, 1937.]

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396. *The Photochemical Union of Hydrogen and Chlorine. Part V. The Reaction at Low Pressures. The Effect of Light Intensity in the Absence of Oxygen.*

By G. V. V. Squire and A. J. Allmand.

(*General Summary of Parts V and VI.*)

The objects of this work were the investigation of the experimental laws governing the kinetics of the photochemical reaction between hydrogen and chlorine in absence of oxygen, and the deduction of a mechanism for it. Existing data were very discordant,

some workers finding proportionality between rate and $I_{abs.}$, others between rate and $I_{abs.}^{0.5}$, whilst Rollefson obtained both relations by variation of the experimental conditions. All were agreed that rate is proportional to hydrogen pressure. We therefore used a method (employed in Part IV but not described) which, whilst limiting our experiments to low hydrogen pressures of the order of 0·1 mm., had advantages from other points of view. Apparatus and technique are described in some detail, and certain points submitted to a critical examination, necessary in view of the unusual nature of the results obtained. In the actual experiments, we worked at eight chlorine pressures, spaced between the limits 0·012—450 mm. A few experiments were done on the effects of added hydrogen chloride. Incident intensities were altered over ranges varying between 2 : 1 and 1600 : 1. Measured velocities varied between extremes of 800 : 1, and calculated quantum yields, referred to hydrogen, over the range 0·05—2000.

The results showed that the exponent n in the equation, rate $= k \cdot I^n$, could vary over the range 0·05—1, the latter figure being found at low chlorine pressures, and the values becoming lower as light intensity and chlorine pressure were increased. At sufficiently high pressures, there was an intensity range over which n, within experimental error, was 0·5. A second, remarkable result, not hitherto recorded, was that rate of reaction and, more markedly, quantum yield passed through a maximum as p_{Cl_2} was increased, and then fell off more and more rapidly, until the quantum yield varied as $p_{Cl_2}^{-2}$. The influence of added hydrogen chloride was complex, but could be analysed into superposed accelerating and retarding effects.

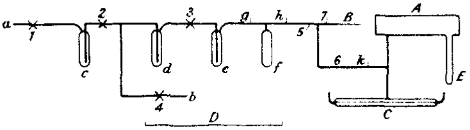
The results are explained by assuming the existence of the radical Cl_3, already postulated in Part IV to account for the effect of wave-length on quantum yield. Its maximum concentration would be controlled by the equilibrium $Cl + Cl_2 \rightleftarrows Cl_3$, assumed to be set up under certain conditions, but more usually not reached. An intensity exponent of unity denotes that the reaction chains are terminated by adsorption of Cl atoms and of Cl_3 radicals on the walls of the vessel. The efficiency of these wall collisions is low, and is depressed still further by adsorbed chlorine and hydrogen chloride. Values of n between 1 and 0·5, found under conditions where three-body collisions are rare events, are due to the gaseous reactions $2Cl_3 \longrightarrow 3Cl_2$ and, probably, $Cl + Cl_3 \longrightarrow 2Cl_2$. Values of n less than 0·5 are the result of localised illumination, and of retarded diffusion of chlorine atoms out of this zone into the dark space in the cell. The kinetic effect of chlorine is, in part, a consequence of the assumption of Cl_3 formation, and the enhanced effects found at high pressures and intensities are due to the same retarded diffusion just mentioned. The suggested mechanism, whilst involving some modification of the results of the quantum-mechanical treatment of the $Cl—Cl_2—Cl_3$ equilibrium by Rollefson and Eyring, appears to be consistent with reported results of other workers, using different experimental conditions.

EXPERIMENTS carried out by Craggs during 1930—1933, already briefly referred to in Part IV (J., 1936, 241), and now to be quoted in more detail, had shown that, in absence of oxygen and at hydrogen pressures of the order of 0·1 mm., the intensity exponent (n in the expression, rate $\propto I_0^n$) was practically unity at the lowest chlorine pressures used, but decreased continually as p_{Cl_2} increased, the lowest value recorded being 0·68 at 166 mm. of chlorine. Such a tendency was in accord with the prediction originally made by Chapman (*Trans. Faraday Soc.*, 1925, **21**, 547) and also with the published note of Chapman and Grigg (*Nature*, 1931, **127**, 584) and the work of Ritchie and Norrish (*Proc. Roy. Soc.*, *A*, **1933**, **140**, 112); but it was directly opposed to the results of Bodenstein and Unger (*Z. physikal. Chem.*, 1931, *B*, **11**, 253), to those obtained at room temperature by Potts and Rollefson (*J. Amer. Chem. Soc.*, 1935, **57**, 1027), and to those published by Bodenstein and Winter (*Sitzungsber. preuss. Akad. Wiss.*, 1936, 1) whilst our own experiments were in progress. In addition, Craggs showed that, above a certain point, increase in p_{Cl_2} markedly retarded the reaction under his conditions of work, whereas neither Bodenstein nor Rollefson noted any such effect. Craggs was controlling his chlorine pressure by immersion of a side limb of the apparatus, containing liquid or solid chlorine, in a constant-temperature bath of refrigerant. If the chlorine condensate were to contain a trace of some volatile inhibitor, this fact would, of course, explain the retardation referred to. But in addition, and as a consequence of the mechanism of chain termination common to all such inhibitors, the intensity exponent n

would tend to rise with increasing p_{Cl_2}, and finally approach once more a value of unity. The trend of the n–p_{Cl_2} graph of Craggs' experiments did, in fact, not exclude such a possible result of a further increase in chlorine pressure. We consequently undertook extensive experiments in order to clear up these points; the results fully confirm those of Craggs, and demonstrate that the marked retarding effect shown by chlorine cannot be due to any adventitious inhibitor.

Experimental.

The technique employed in all this work, including the experiments described in Part IV, was based on that devised by Rollefson (*J. Amer. Chem. Soc.*, 1929, **51**, 770). The apparatus used, modified in minor details from time to time, consisted essentially of an insolation vessel (*A*), provided with means of introducing hydrogen (*B*) and measuring its pressure before and after reaction (*C*), of introducing chlorine (*D*) and regulating its pressure during the reaction, and of condensing out hydrogen chloride and chlorine after the reaction (*E*). The figure shows diagrammatically the form used in the experiments of 1935—1936. Evacuation was effected



through *a* by means of a mercury diffusion pump backed by a Hyvac pump. The trap *c*, immersed in liquid air, protected the apparatus from mercury vapour and the pump from chlorine; 1, 2, 3, and 4 were mercury-sealed taps lubricated with metaphosphoric acid in accordance with instructions kindly communicated by Mr. D. L. Chapman. Before being turned, they were warmed to about 50° by means of an electrically heated coil of wire wound round the barrel. In the earliest experiments, similar taps were also inserted at points 5 and 6, but they were eliminated later, as they were found to cause trouble during long-continued runs.

A was a cylindrical quartz vessel with plane ends (25 cm. × 5 cm. diameter). Connection with the glass parts of the apparatus was made by quartz–soda glass fused joints; *B* was a small palladium tube sealed on to glass by means of a platinum junction. Hydrogen passed readily through this when heated in a small Bunsen flame. If larger quantities were required, the palladium was jacketed by a quartz tube, hydrogen passed through the annular space, and the whole heated in a Bunsen flame. Special experiments showed no appreciable reaction to take place between the chlorine and the palladium, nor any combination of hydrogen and chlorine to be caused by the palladium surface. *C* was a Pirani gauge with a glass-covered mercury thread, constructed according to Rollefson (*loc. cit.*, p. 804). This proved very satisfactory in use. The glass capillary was about 20 cm. long, and its containing tube about 10 mm. in diameter. The resistance of the mercury thread at room temperature was of the order of 20Ω, and, with the balancing resistances used, the reaction system evacuated, and liquid air around *E*, some 3—4 volts (the zero voltage v_0) were necessary across the bridge for a balance with different gauges. This figure sometimes showed variations of the order of 0·04—0·08 volt from series to series, probably due to the effect of baking out on a minute gas bubble present in the mercury thread. With hydrogen gas in the system, a higher voltage v was required. When compared against known hydrogen pressures, by means of a McLeod gauge, the plot of p_{H_2} against $f(v) = (v^2 - v_0^2)/v_0^2$ was slightly concave to the pressure axis; v_0 was found to vary with temperature, and the gauge was consequently kept at a constant temperature by means of a water-jacket. The estimated errors in the pressure values were of the order of 0·002 mm. at 0·2 mm. and 0·0005 mm. at 0·02 mm. At still lower pressures they were relatively greater, as the voltmeter used could only be read to 0·01 volt.

For *D*, a cylinder of liquid chlorine, provided with a silver-lined needle valve, was sealed on at *b* by means of a metal–glass joint. With the apparatus evacuated, tap 2 closed, and liquid air on *d*, chlorine was admitted and permanent gas pumped off. The chlorine was then distilled into *e* and back again into *d*, the head and tail fractions, in all about half of the original condensate in *d*, being collected in *c*. This procedure was repeated, and the final middle fraction from *e* transferred to *E*, and used for the actual experiments. Towards the end of the work, a modified technique was employed. The chlorine, after fractionation, was distilled from *e* into *f*,

and a capillary constriction at *g* sealed off. Melting chlorobenzene (m.p. 228° K.) was placed round *f*. After sufficient time had been allowed for the apparatus to become filled with chlorine at 450 mm. pressure (the vapour pressure of liquid chlorine at 228° K., see Table I), the reaction zone was sealed off at *h*. By working in this way, no chlorine condensate was present during experiments at 450 mm. of chlorine, and only minimum amounts when using lower values of p_{Cl_2}.

E consisted of a tube of 9 mm. internal diameter sealed on to *A*. During an experiment, its lower end was immersed in a bath of some half-molten refrigerant of known m. p., the chlorine pressure inside the reaction space thus being kept constant. Great care was taken to ensure the purity of the liquids used. Their m. p.'s (from I.C.T.) and the corresponding chlorine pressures interpolated from Harteck's data (*Z. physikal. Chem.*, 1928, **124**, 21) are contained in Table I.

TABLE I.

Refrigerant.	Temp. (° K.).	Pressure (mm.).	Refrigerant.	Temp. (° K.).	Pressure (mm.).
Allyl chloride	136·6	0·012	Ethyl acetate	189·6	45·7
Methyl*cyclo*hexane	146·6	0·11	Ethyl propionate ...	199·3	82·6
Carbon disulphide ...	161·4	1·7	Chloroform	209·7	166
Toluene	178·5	13·0	Chlorobenzene	228	450

It was found necessary to stir the refrigerant frequently to maintain it at a constant temperature as measured by a platinum resistance thermometer, and where very long runs were concerned a method was devised of syphoning more liquid air on to the refrigerant at regular intervals. Sleeve-like insertions of black cloth in the sides of the light-tight box enclosing the reaction system allowed of these and other necessary manipulations. When a measurement of hydrogen pressure was being taken before and after an experiment, *E* was immersed in liquid air up to a fixed depth, and the gauge reading recorded when constant. Preliminary experiments showed condensed hydrogen chloride to exert, at liquid-air temperature, a pressure equivalent to 0·0018 mm. of hydrogen on the Pirani gauge. The corresponding correction was made when required.

In carrying out a series of experiments, the apparatus was first baked out and evacuated in the usual way until the gauge reading was constant. Chlorine was admitted as described, the apparatus sealed off at *h*, liquid air adjusted around *E*, and v_0 read off. After hydrogen had been admitted, and its initial pressure read, the liquid air around *E* was replaced by the constant-temperature bath giving the required chlorine pressure and, after 20 mins'. standing (10 mins. used in the earlier experiments were found to be insufficient to secure uniformity of hydrogen pressure throughout the apparatus), insolation was commenced. At its conclusion, liquid air was replaced around *E*, and the new pressure reading taken. The apparatus was then ready, after readjustment of the chlorine pressure, for another insolation. More hydrogen was admitted, as and when required, through *B*. The supply of chlorine present at the start in *E* sufficed for all the experiments required in a particular series of runs. Hydrogen chloride accumulated in the apparatus, its amount at any instant being known from the total quantity of hydrogen which had been consumed. In the earlier experiments, before the procedure of sealing off at *h* was adopted, it was removed by evacuation as required. Higher hydrogen chloride pressures were obtained by the admission, in stages, of the calculated pressure of hydrogen and its photocombination with chlorine.

The apparatus used in the experiments of 1930—1933, in addition to quartz, sometimes employed reaction vessels (*A*) of glass (24—27 cm. × 2·7—2·9 cm. diameter). In some experiments, a tap was inserted at 7, the palladium tube *B* thus at no time coming into contact with chlorine. In others, after filling with hydrogen, the reaction space was sealed off at *k*. Whilst the first precaution was subsequently shown to be unnecessary, the sealing off of the reaction zone, as already mentioned, was certainly advantageous.

In the later work, we used as light sources a 1000-watt metal-filament lamp and a quartz-mercury arc, both running on the 100—110 volt constant-voltage circuit, the light being passed through a blue Corning glass filter (G 40 d), of which the spectral transmission had been carefully measured at intervals of 100 A. The maximum figure lay at 5000 A. The beam was rendered approximately parallel and of the required diameter by means of two quartz lenses and diaphragms before entering the cell, and, on leaving, was concentrated by means of a third lens on a calibrated 2-cm. Moll surface thermopile, the *E.M.F.* produced being measured by a micro-potentiometer. Various devices were employed to reduce the intensity. A "neutral" wedge *

* This proved to have considerable selective absorption, which made impossible any quantum-efficiency calculations. On this account, its use was discontinued.

(see Part I; J., 1930, 2694) was first used in conjunction with the metal-filament lamp, and in experiments with the mercury arc, an adjustable sector diaphragm on the first lens. In order to secure a more considerable variation in intensity, copper-gauze screens were found to be the most convenient, as many as four being clamped together for the lowest intensities, and they were exclusively used at the end of the work. In all cases, the intensity reduction was directly measured by means of the thermopile and either potentiometer or galvanometer. The earlier experiments employed a quartz–mercury arc, together with 1000-watt and 100-watt metal-filament lamps. The usual filter was a soda-glass plate. The light flux was varied by the sector diaphragm method, the intensity ratio being determined as above.

It should be emphasised that insolation was always effected by a beam of light passing axially down the centre of the cell. Its diameter varied, but in no case was the whole cross-section of the reaction cell illuminated.

Before passing to detail, certain general features of the results will be considered. In agreement with Rollefson, it was found that the reaction is essentially of the first order with respect to hydrogen, and that therefore a plot of log p_{H_2} against time of insolation tends to be linear. The expression $100(-\Delta \log p_{H_2})/t$, where p_{H_2} is expressed in mm. and t in minutes, will be termed the *slope*, and, at constant incident intensity, is a measure of the effect of chlorine and of hydrogen chloride on the rate, or, when divided by the corresponding rate of quantum absorption, on the quantum efficiency. Favourable examples of the degree of constancy of slope found in a single experiment follow.

Expt. 24.

Cl_2, 13·0 mm.; initial HCl, 0·00 mm.

t.	p_{H_2}.	Slope.
0	0·1315	3·34
3	0·1044	3·15
10·5	0·0606	3·46
20·5	0·0273	3·88
35·5	0·00715	3·40
55·0	0·00155	
Mean value of slopes		3·45
Mean slopes over whole run...		3·51

Expt. 53.

Cl_2, 1·7 mm.; initial HCl, 0·10 mm.

t.	p_{H_2}.	Slope.
0	0·0925	4·13
7	0·0475	3·89
17	0·0194	4·00
28	0·00705	3·81
37	0·0032	
Mean value of slopes		3·96
Mean slope over whole run ...		3·95

Expt. IX, e.

Cl_2, 45·7 mm.; initial HCl, 2·485 mm.

t.	p_{H_2}.	Slope.
0	0·1805	5·22
5	0·0990	5·24
10	0·0541	4·89
15	0·0308	5·12
20·5	0·0161	(4·22)
25·5	0·0099	
Mean slope		5·12

Expt. X, g.

Cl_2, 166 mm.; initial HCl 1·16 mm.

t.	p_{H_2}.	Relative intensity.	Slope.
0	0·1633	5·65	3·26
5	0·1122	1·00	1·62
10	0·0931	1·00	1·63
15	0·0772	5·65	3·08
20	0·0541		
Mean slopes			3·17 and 1·625
Value of n			0·39

Frequently, the concordance inside a given run was, however, less good, and the slopes showed irregular variations of the order of 15—20%. The causes of these fluctuations were, we think, two-fold—on the one hand, variations in catalytic power of the walls of the reaction vessel and in the degree of convection taking place in the reacting gases, and, on the other, changes in temperature of the condensed chlorine in E (see fig.). One other apparent anomaly must be mentioned. In a number of cases, when hydrogen chloride was present, the slope fell off as the hydrogen pressure became very low. The most striking examples were the following, for which an explanation is offered in Part VI.

Expt. 21.

Cl_2, 13·0 mm.; initial HCl, 10·8 mm.

t.	p_{H_2}.	Slope.
0	0·0154	6·70
7	0·00523	1·87
18	0·00326	

Expt. 46.

Cl_2, 0·012 mm.; initial HCl, 6·9 mm.

t.	p_{H_2}.	Slope.
0	0·260	1·60
40	0·0595	1·76
78	0·0127	0·67
101	0·0089	

Expt. 48.

Cl_2, 1·7 mm.; initial HCl, 46·2 mm.

t.	p_{H_2}.	Slope.
0	0·246	11·9
4	0·0825	12·3
9	0·0200	7·51
12	0·0119	6·07
19	0·00447	

Two further points must be referred to, which concern in principle the validity of our experimental method, *viz.*, the facts that (i) the closed system is not at a uniform temperature during an insolation, the temperature gradient being accentuated during the measurement of

hydrogen pressures, and (ii) during reaction, hydrogen will arrive in the insolated zone from the rest of the apparatus by diffusion and convection. We have gone very fully into the possibility that the values of our slopes might be falsified by these two circumstances, and have concluded that any errors are of a minor order. The correction involved in the first case becomes very small when the fact that the volume of the cooled zone is perhaps 5% of the total volume is taken into account. Direct observations on the rate and extent of pressure change taking place when the end of E is immersed in liquid air, when one refrigerant is replaced by another, and when hydrogen is admitted to the reaction zone with liquid air on E all confirm the conclusion that any error can be neglected. With regard to the second point, we are assuming that, for all practical purposes, p_{H_2} is constant throughout the whole apparatus at any moment. In the later experiments, the approximate volumes of the different parts of the apparatus were: reaction cell (central portion only illuminated), 490 c.c.; side tube E, 80 c.c.; Pirani gauge and remainder of system, 90 c.c. Similar relations held in the earlier experiments. Quite apart from convection, which played an important rôle at all save the highest chlorine pressures, calculation of diffusion rates shows that the hydrogen content of E would not differ appreciably during the insolation from that in the reaction cell. The case of the Pirani gauge with its associated lengths of 5-mm.-bore tubing is more difficult, and it is best here to consider the general nature of the results of all the experiments. If the observed slopes are in error owing to retarded diffusion of hydrogen, it can be shown that, in any insolation, the effect will be greater (i) the greater the ratio p_0/p of the initial to the final pressure, (ii) the higher the chlorine and hydrogen chloride pressures, (iii) the greater the rate of reaction of hydrogen (high intensities and gas sensitivities), and (iv) the lower the initial hydrogen pressure. *No such correlation is visible in our data.* We conclude that, whilst there must necessarily have been a hydrogen-pressure gradient in the reaction system during our experiments, hydrogen passed sufficiently rapidly from the dead space into the reaction zone to avoid any serious distortion of the results.

Results

In what follows, the later (1935—36) experiments are denoted by series numbers and letters, *e.g.*, VII, c; IX, f; and the earlier ones (1930—33) by numbers with the number of the series in parentheses, *e.g.*, 29 (4); 36 (7). Table II comprises all the data for chlorine pressures up to 13 mm., Table III the earlier results with 45·7 and 166 mm., and Table IV the more recent data obtained at such higher pressures; W and Hg denote respectively metal-filament and mercury-arc lamps. The difference between Σp, the total pressure, and p_{Cl_2} is accounted for to the extent of about 0·1 mm. by hydrogen, the remainder being hydrogen chloride. In Table IV absorbed intensities are given in quanta per second, calculated from thermopile deflexions obtained with the empty cell, the energy distribution in the light source, the measured filter transmissions, and the known extinction coefficients of chlorine. In the case of the mercury-arc radiation, the only two lines transmitted by the filter and appreciably absorbed by chlorine were 4050 and 4360 A. In the case of the tungsten-filament lamp, which burnt at about 3040° K., the maximum quantum intensity of the radiation transmitted by the filter lay at 5200 A., whilst the region of maximum quantum absorption by the chlorine moved from 4200 to 4400 A. as p_{Cl_2} increased from 45·7 to 450 mm. This statement refers essentially to the experiments of Series X; owing

TABLE II.

Expt.	p_{Cl_2} (mm.).	Σp (mm.).	Light source.	Filter.	Intensity ratio.	Mean slopes.	Slope ratio.	n.
58 (11)	0·11	0·97—1·30	W	None	10	0·22 : 0·024	9·2	0·96
VII, f	—	0·85—0·87	Hg	6 mm. soda glass	4·60	0·106 : 0·024	4·46	0·98
13, 15 (3)	1·7	2·4 —2·6	—	—	10	2·4 : 0·25	9·6	0·98
37 (7)	—	3·1	—	—	4·35	0·71 : 0·17	4·2	0·98
VII, c	—	2·1 — 2·2	—	—	4·60	1·22 : 0·24	5·1	1·06
VII, e	—	2·3 — 2·4	—	—	—	0·98 : 0·23	4·26	0·95
IX, f	—	5·0 — 5·1	—	—	5·45	1·54 : 0·32	4·81	0·93
12, 14 (3)	13·0	13·6 —13·8	—	—	10	11 : 1·4	7·9	0·90
30 (5)	—	13·2	—	—	4·35	7·8 : 2·0	3·9	0·93
31 (5)	—	13·1	—	—	—	6·9 : 1·8	3·8	0·91
36 (7)	—	14·0	—	—	—	5·2 : 1·4	3·7	0·89
VI, e	—	17·6	—	Corning G 40 d	4·60	1·99 : 0·57	3·5	0·82
73 (13) *	—	332	—	6 mm. soda glass	4·35	1·09 : 0·38	2·9	0·72

* In this experiment, there were present 318 mm. of HCl and also 0·075 mm. of O_2. This is the only occasion on which oxygen was present.

to the faulty nature of the "neutral wedge" employed in Series IV, as also in X, e and X, j, no absolute calculations can be made, and the region of maximum absorption will certainly lie at

TABLE III.

Expt.	p_{Cl_2} (mm.).	Σp (mm.).	Light source.	Filter.	Intensity ratio.	Mean slopes.	Slope ratio.	*n*.
32 (5)	45·7	46·1	Hg	6 mm. soda glass	4·35	13·0 : 3·7	3·5	0·85
34 (7)	—	45·9	—	—	—	11·8 : 3·7	3·2	0·79
35 (7)	—	46·3	—	—	—	10·4 : 3·3	3·2	0·79
38 (7)	—	55·9	—	—	—	10·7 : 3·2	3·3	0·81
129—131 (22)	—	46·6—46·7	—	*	1·93	0·886 : 0·562	1·58	0·70
39 (7)	166	176·5	—	6 mm. soda glass	4·35	3·5 : 1·2	2·9	0·70
41 (7)	—	177·4	—	—	—	3·0 : 1·1	2·7	0·68

* Radiation of wave-length 4360 A. was used in these experiments, employing a large monochromator. See Part IV.

TABLE IV.

Corning G 40 d filter in use throughout.

Expt.	Light source.	log quanta absorbed per sec.	Intensity ratio.	Mean slopes.	Slope ratio.	*n*.
		(*a*) p_{Cl_2} 45·7 mm.; Σp 47·3—49·2 mm.				
IV, i	W	? ?	4·49	2·58 : 0·63	4·10	0·94
V, c	Hg	14·051 : 13·678	2·36	4·66 : 2·38	1·96	0·78
V, d	—	13·299 : 12·926	—	0·93 : 0·42	2·21	0·92
V, e	—	13·299 : 12·926	—	1·33 : 0·63	2·11	0·87
V, f	—	13·299 : 12·926	—	1·26 : 0·55	2·29	0·96
VI, a	—	14·051 : 13·388	4·60	5·61 : 1·77	3·17	0·76
IX, e	—	14·051 : 13·299	5·65	5·12 : 1·23	4·16	0·82
		(*b*) p_{Cl_2} 82·6 mm.; Σp 84·1—87·8 mm.				
VI, d	Hg	14·249 : 13·586	4·60	6·69 : 2·72	2·46	0·59
VI, h	—	13·497 : 12·834	—	2·28 : 0·67	3·40	0·80
IX, a	—	14·249 : 13·497	5·65	4·67 : 1·22	3·83	0·78
IX, b	—	13·875 : 13·123	—	2·44 : 0·55	4·44	0·86
IX, c	—	13·497 : 12·745	—	1·25 : 0·28	4·46	0·86
IX, d	—	13·123 : 12·371	—	0·62 : 0·12	5·17	0·95
X, k	W	15·650 : 14·898	—	16·8 : 7·3	2·30	0·48
X, l	—	15·277 : 14·525	—	15·3 : 5·7	2·68	0·57
X, m	—	14·898 : 14·146	—	6·72 : 2·27	2·96	0·63
		(*c*) p_{Cl_2} 166 mm.; Σp 167·1—171·0 mm.				
IV, h	W	? ?	4·49	1·62 : 0·69	2·35	0·57
V, b	Hg	14·435 : 14·062	2·36	1·99 : 1·58	1·26	0·27
VI, g	—	14·435 : 13·772	4·60	3·15 : 1·86	1·69	0·34
IX, g	—	14·435 : 13·683	5·65	2·27 : 0·96	2·36	0·50
IX, h	—	14·061 : 13·309	—	1·32 : 0·415	3·18	0·67
IX, i	—	13·683 : 12·931	—	0·73 : 0·255	2·86	0·61
X, f	W	15·862 : 15·110	—	3·12 : 2·83	1·10	0·055
X, g	—	15·110 : 14·358	—	3·17 : 1·625	1·95	0·39
X, h	—	14·737 : 13·985	—	2·45 : 1·12	2·19	0·45
X, i	—	14·472 : 13·720	—	1·45 : 0·50	2·90	0·61
X, j *	—	? ?	—	0·37 : 0·093	4·0	0·80
		(*d*) p_{Cl_2} 447·5—450 mm.†; Σp 450·2—453·1 mm.				
IV, a	W	? ?	4·49	0·314 : 0·162	1·94	0·44
IV, g	—	? ?	—	0·314 : 0·161	1·95	0·44
V, a	Hg	14·585 : 14·212	2·36	0·364 : 0·286	1·27	0·28
VI, f	—	14·585 : 13·922	4·60	0·567 : 0·372	1·52	0·27
VI, i	—	13·833 : 13·170	—	0·309 : 0·177	1·75	0·37
VI, j	—	13·460 : 12·797	—	0·229 : 0·115	1·99	0·45
IX, j	—	13·833 : 13·081	5·65	0·076 : 0·027	2·81	0·60
X, a	W	16·095 : 15·343	—	0·83 : 0·72	1·15	0·081
X, b	—	15·343 : 14·591	—	0·79 : 0·43	1·84	0·35
X, c	—	14·970 : 14·218	—	0·53 : 0·26	2·04	0·41
X, d	—	14·737 : 13·985	—	0·39 : 0·175	2·23	0·46
X, e *	—	? ?	—	0·060 : 0·021	2·85	0·60

* The "neutral wedge" was used in X, e and X, j in order to reduce the intensities still further.

† The rates of quantum absorption in this section are, in all cases, those calculated for a chlorine pressure of 450 mm.

longer wave-lengths. Attention is drawn to the very high range of intensities covered in some of these experiments, more particularly in Series X, where the extreme values used when working with 166 and 450 mm. of chlorine were about 1000 : 1 and 1600 : 1 respectively. The highest and the lowest slope recorded in the tables are 16·8 and 0·021, a ratio of 800 : 1. These facts demonstrate the flexibility of the experimental method.

Discussion.

As already remarked, the observed slopes within a single experiment frequently showed variations of the order of 20%. Experiments in the same series, carried out under supposedly identical conditions [*e.g.*, Tables II and III, Expts. VII, c, e; 39, 41 (7); Table IV, Expts. IX, a—d; IV, a, g; X, a, b] show a degree of concordance which, although very variable, is of the same nature. If experiments in different series, *i.e.*, with different chlorine fillings, are compared, agreement is less good, the result of variations in catalytic properties of the cell walls. For example, the slopes in Series VI are always greater than those in Series V and IX, the latter approximating fairly closely to one another. The biggest discrepancy is that shown by Expts. VI, i and IX, j [Table IV (*d*)]. Moreover, for the same rate of quantum absorption, slopes in Series X are always less than those in the other series.

The first conclusion concerns the relation between p_{Cl_2} and n at constant incident intensity. The tendency found in the early experiments is fully confirmed by the later measurements, and it can be stated that, within the limits of experimental error, n falls continuously under our working conditions as p_{Cl_2} is increased up to the maximum of 450 mm. This is clearly shown in Table V, containing the results of all series of measurements in which three or more different chlorine pressures were experimented on at two identical incident intensities.

Table V.

Values of n.

Expts.	p_{Cl_2} (mm.). 1·7.	13.	45·7.	82·6.	166.	450.
34—39, 41 (7)	0·98	0·89	0·79—0·81	—	0·68—0·70	—
IV, a, g, h, i	—	—	0·94	—	0·57	0·44
V, a, b, c	—	—	0·78	—	0·27	0·25
VI, a, d, e, f, g	—	0·82	0·76	0·59	0·34	0·27
IX, a, e, g	—	—	0·82	0·78	0·50	—
IX, c, i, j	—	—	—	0·86	0·61	0·60
X, a, f, k	—	—	—	0·48	0·055	0·081
X, b, g, m	—	—	—	0·63	0·39	0·35

It will be noted that a figure of less than 0·5 is found even with 82·6 mm. of chlorine, that at 450 mm. this is the normal result, and that values below 0·1 are recorded.

No considerable variations of Σp as distinct from p_{Cl_2} are contained in Tables III and IV. In Table II, however, Expt. 73 shows the abnormally low n value of 0·72, which can only be due to the high pressure of hydrogen chloride. A small amount of oxygen was also present. This would not be expected to play any part at the low pressures of hydrogen employed, and if it were to affect the value of n, it would certainly raise, not lower it.

Table IV brings out the second main result, *viz.*, that in any given series of experiments [V in section (*a*); VI, IX, and X in section (*b*); IX and X in section (*c*); VI and X in section (*d*)], n decreases as the rate of absorption of light increases, the only exception being found in Expts. IX, h, i. The abnormally low values of n just referred to, where a 5·65-fold intensity increase only alters the reaction rate by 10—15%, are found at very high light intensities.

A further very important conclusion, which follows from an examination in Tables II—IV of the actual slopes found in the experiments mentioned in Table V, is that, at constant intensity, the rate of reaction passes through a maximum and then falls off as p_{Cl_2} increases.

The significance of these facts will be discussed in the succeeding paper, and one further point only will now be considered. The results show that n falls as the rate of light absorption increases. Obviously it is the absorption rate per unit volume which is significant. In the experiments of Table IV, employing polychromatic light of widely varying extinction coefficient, there are considerable differences between these rates at different depths in the

reaction cell. These differences increase as p_{Cl_2} increases, and are more important for mercury than for tungsten radiation.

Table VI contains the percentages of the total quanta absorbed by the reacting gases, calculated for successive 5-cm. layers commencing from the front of the cell, for both filtered light beams, and for the four highest pressures used. In these, as in all other similar calculations, the radiation of the metal-filament lamp has been treated by dividing it up into sections each comprising 100 A., and using for each section the appropriate

TABLE VI.

Percentage distribution of absorbed quanta in 25-cm. reaction cell.

		1.	2.	3.	4.	5.
45·7 mm.	Hg	23·2	21·5	20·0	18·4	17·0
	W	22·6	21·3	19·8	18·7	17·6
82·6 mm.	Hg	25·8	22·4	19·6	17·1	15·1
	W	24·7	21·9	19·6	17·7	16·1
166 mm.	Hg	31·5	24·0	18·5	14·5	11·5
	W	28·8	22·9	18·9	15·9	13·6
450 mm.	Hg	49·0	24·8	13·6	7·9	4·8
	W	38·3	23·2	16·3	12·3	9·9

incident intensity and extinction coefficient. In this way, for example, it is calculated that, at 450 mm. of chlorine, the maximum intensity of the absorbed light lies, in the first 5 cm., at 4250—4300 A., but in the last 5 cm. at 4700 A.

It is plain that the experimental value of *n* is an average figure for the whole reaction vessel, the true value increasing on passing from front to back. A comparison between the dependence of *n* on the absorbed intensity, as shown in Table IV, and the relative rates of quantum absorption in the first and the back layer, as given in Table VI, suggests that, in practice, this spatial variation of *n* should be negligible at 45·7 and 82·6 mm., perceptible at 166 mm., and very marked at 450 mm. Moreover, in the last case, it should be far more important for mercury than for tungsten radiation, the ratios for the absorption rates in the first and the back layer being 10·2 and 3·9 respectively. One would then expect that, at the same rate of quantum absorption, higher values of *n* should be obtained, working with 450 mm. of chlorine, when using the metal-filament lamp than when using the mercury arc. If, as before, we regard IX, j as an exceptional result, this is certainly so. It is also the case at 166 mm., and is plainly so at 82·6 mm., where no difference would be expected. Experiments from Series X are involved in all these comparisons, and it has already been mentioned that the slopes in this case, referred to the rates of quantum absorption, are relatively low. This being so, it is perhaps better to compare the *n* values for experiments with the two light sources which give approximately the same slope. When this is done, it is found that mercury-lamp experiments still give lower *n* values at 450 mm. (*e.g.*, V, a; VI, f; X, b, c, d: VI, i; IV, a, g; X, d), but that the differences at the other pressures are all plausibly covered by the errors of experiment and of comparison.

SUMMARY.

(1) The experimental technique employed in Parts IV—VI of this investigation is described, illustrated, and critically discussed.

(2) Results are tabulated of the effect of variation of intensity on the rate of reaction in oxygen-free hydrogen–chlorine mixtures, the hydrogen pressure being of the order of 0·1 mm., whilst the chlorine pressure varied between 0·11 and 450 mm.

(3) The intensity exponent *n* was found to vary between limits of 1 and 0·05, becoming less the higher the chlorine pressure and the higher the incident intensity.

(4) Under otherwise comparable conditions, lower values of *n* were obtained when using strongly absorbed (mercury arc) than when using weakly absorbed (tungsten filament) radiation.

(5) As the chlorine pressure increased at constant intensity, the rate of reaction passed through a maximum and then fell off.

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397. *The Photochemical Union of Hydrogen and Chlorine. Part VI. The Mechanism of the Reaction at Low Hydrogen Pressures in Absence of Oxygen.*

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Experimental.

In Part V (preceding paper), it was stated that, at constant incident intensity, the rate of reaction under our conditions of experiment rose to a maximum as p_{Cl_2} increased, and then fell off. In the earlier work, the maximum was found at either 13 or 45·7 mm., whilst in a large number of experiments, carried out under a variety of conditions, the " slope " (see Part V) at 1·7 mm. was always less than that at 13 mm. In the more recent work, the maximum rate was found at 82·6 mm. of chlorine in one case, whilst in other, less complete sets of measurements, it lay at 45·7 mm. Moreover, in agreement with the observed relation between absorbed intensity and *n*, it moved towards high chlorine pressures as the incident intensity decreased [*e.g.*, Part V, Table IV, (*a*) and (*c*) : Expts. IV, h, i; VI, a, g].

This retarding effect of chlorine is shown to its full extent when, at constant incident intensity, quantum efficiencies are compared. The majority of the later and many of the earlier experiments can be treated in this way, the necessary data (absolute intensity of light beam, spectral energy distribution therein, extinction coefficients of chlorine, slopes, volume of reaction zone) being available. Table I contains these γ values, referred to hydrogen and calculated for a hydrogen pressure of 0·1 mm., for all cases where three or more chlorine pressures can be compared with one another. Expts. 56 and 57 are included for a particular reason. Where pairs of values are quoted, the second refers to the lower of two absorbed intensities, the ratio of which is given in the last column.

In every case, γ rises as intensity decreases, and to a greater degree the higher the chlorine pressure. The absolute rates of quantum absorption for the latter experiments are given in Table IV of Part V. In the mercury-arc experiments, the absorbed intensities were higher in the earlier than in the later work. In qualitative agreement with this difference, the γ values are lower in the earlier experiments. To this statement there is one marked exception. In

Table I.

Values of quantum efficiency at p_{H_2} = 0·1 *mm. and at different chlorine pressures.*

Expts.	Chlorine pressure, mm. 0·012.	0·11.	1·7.	13·0	45·7.	82·6.	166.	450.	
24—26 (4)	—	—	11·1	12·2	6·9	—	—	—	
34—39, 41 (7)	—	—	13·2	18·2	22·4	—	4·8	—	} 4·35
	—	—	13·7	21·3	30·1	—	7·4	—	
42, 43, 52 (8) ...	270	—	147	55	—	—	—	—	
56, 57 (10)	—	—	—	50	14	—	—	—	
58—62 (11) ...	—	(1·00)	(1·01)	(1·09)	(0·77)	—	(0·17)	—	
V, a, b, c	—	—	—	—	35·0	—	6·16	0·80	} 2·36
	—	—	—	—	42·3	—	11·6	1·49	
VI, a, d, e, f, g	—	—	—	46·3	42·1	32·6	9·75	1·25	} 4·60
	—	—	—	61·5	61·9	59·5	26·5	3·76	
IX, a, e, g	—	—	—	—	38·4	22·2	7·02	—	} 5·65
	—	—	—	—	52·1	32·9	16·8	—	
IX, c, i, j	—	—	—	—	—	33·6	12·8	0·94	} 5·65
	—	—	—	—	—	42·2	25·2	1·90	
X, a, f, k	—	—	—	—	—	3·18	0·36	0·056	} 5·65
	—	—	—	—	—	7·75	1·85	0·27	
X, b, g, m	—	—	—	—	—	7·17	2·08	0·30	} 5·65
	—	—	—	—	—	13·7	6·1	0·93	

Note.—The pairs of values enclosed within dotted frames were obtained by insolation with the same intensity in different experiments.

Expts. 42—54 and 56—57 (two different series), a quartz–mercury lamp without any filter was used, and the rates of quantum absorption were consequently unusually high. In spite of this, the values of γ at low pressures of chlorine were the highest observed. The figures in parentheses

for Expts. 58—62 (glass apparatus; tungsten-filament lamp; no filter) are relative values only, no absolute intensity measurements being available.

With the exception of the remarkable group of results given by Expts. 42—57, the maximum γ value is seen to fall sometimes at 13·0, sometimes at 45·7 mm. of chlorine, and there are indications that, the lower the intensity, the higher would be this optimum pressure. At higher chlorine pressures, γ falls off ever more and more steeply.

Table II contains the "order" according to which the chlorine takes part in the reaction at constant incident intensity when p_{Cl_2} increases from 82·6 to 166, and from 166 to 450 mm., effects due to the changed absorption of light being eliminated by using the equation $\gamma_{p_1}/\gamma_{p_2} = (p_2/p_1)^m$. The first value of m is derived from the experiments at the higher intensity.

TABLE II.

82·6—166 mm. Expts.	m.	166—450 mm. Expts.	m.
VI, d, g	1·73, 1·16	V, a, b	2·05, 2·06
IX, a, g	1·65, 0·96	VI, f, g	2·06, 1·96
IX, c, i	1·38, (0·75)	IX, i, j	(2·62), (2·59)
X, f, k	(3·12), 2·05	X, a, f	1·87, 1·93
X, g, m	1·77, 1·16	X, b, g	1·94, 1·89
		X, c, h	2·08, 2·00
		X, d, i	1·94, 1·66

Some discrepant figures have been enclosed in parentheses. We cannot account for them, but it may be remarked that attention was drawn in Part V to the abnormal results of IX, i, j, and that the results obtained at the higher intensities in X, a, k showed an unusual lack of reproducibility. Apart from them, it is clear that γ varies in proportion to the inverse square power of p_{Cl_2} as this increases from 166 to 450 mm., whilst in the interval 82·6—166 mm., the kinetic "order" of the chlorine lies between -1 and -2, the latter figure being approached as the intensity increases.

TABLE III.

p_{Cl_2} = 0·012 mm. Series 8. Expt.	p_{HCl}.	Slope.	p_{Cl_2} = 0·11 mm. Series 11. Expt.	p_{HCl}.	Slope.	p_{Cl_2} = 1·7 mm. Series 8. Expt.	p_{HCl}.	Slope.
52	0·0	0·22	58	0·0	0·21	43	0·28	15·1
46	6·9	1·6	62, a	3·36	0·34	45 b	6·7	11·8
51	8·6	1·4	62, b	4·74	0·50	48, 50	46·2	6·6—12·2 *

p_{Cl_2} = 1·7 mm.

Series 3. Normal incident intensity.			Series 3. Much reduced incident intensity.			Series 4.		
13	0·46	2·2—3·7 (mean 2·8)	17	1·3	0·022	25	0·26	0·60
20	10·8	2·2	19	10·4	0·032	29	10·9	1·7
22	11·0	2·9						

p_{Cl_2} = 13·0 mm.

Series 3. Normal incident intensity.			Series 3. Much reduced incident intensity.			Series 4.		
12	0·12	11·2	16	1·2	0·16	24	0·0	3·45
23	11·3	12·6	18	10·0	0·20	28	10·7	5·4
Series 7.			**Series 8.**			**Series 13.†**		
36	0·80	5·2	42	0·0	26	68	0·80	5
40	10·7	6·34	47	45·4	14	73	318	0·38

p_{Cl_2} = 45·7 mm.

Series 4. Expt.	p_{HCl}.	Slope.	Series 7. Expt.	p_{HCl}.	Slope.
26	0·44	3·4	34, 35	0—0·4	10·4—11·8
27	10·5	5·5	38	10·0	10·7

* Very irregular results. † Traces of oxygen present.

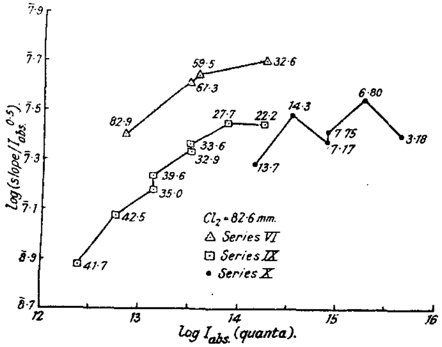
The only other experimental data to be considered concern the effect of added hydrogen chloride. A number of such experiments were made during the earlier work, and the results are collected in Table III (pressures of hydrogen chloride in mm.). It is plain that, at the two lowest chlorine pressures used, a few mm. of added hydrogen chloride accelerate the reaction. The effect of the addition of 10—11 mm. on the reaction rate at higher chlorine pressures is, at first sight, not very clear, but inspection shows two factors to be involved, *viz.*, (i) the rate of reaction in absence of added hydrogen chloride, and (ii) the chlorine pressure. Addition of hydrogen chloride tends to accelerate a slow reaction, to have less effect as this rate becomes greater, and to retard a rapid reaction. Quite generally, under the same conditions of illumination, the slopes found in the different series increased in the order $4 < 7 < 3 < 8$, being very high in the last case (Expts. 42, 43, 52 of Table I). The relative effects of adding 10 cm. of hydrogen chloride at different chlorine pressures are all in accord with this progression; *e.g.*, at $p_{Cl_2} = 1{\cdot}7$ mm., there is a three-fold acceleration in series 4, no appreciable effect in 3, and actually a retardation in 8 when 6·7 cm. are added. The evidence at the other chlorine pressures is similar. Differences in slope due to differences in incident intensity are related in the same way to the effect of added hydrogen chloride, as is seen in Series 3, experiments at 1·7 and 13 mm. of chlorine. The effect of p_{Cl_2}, when the experiments at 0·012 and 0·11 mm. are taken into account, can also not be doubted, notwithstanding the relative results at 1·7 and 13 mm. of chlorine in Series 3 (normal intensities) and at 13 and 45·7 mm. in Series 4. The lower p_{Cl_2}, the greater the accelerating effect of a few mm. of added hydrogen chloride.

We have very few results at higher hydrogen chloride pressures. In Series 8, 46 mm. of the gas reduce the velocities at p_{Cl_2} values of 1·7 and 13 mm. In view of what has been said, it is by no means certain that a similar retardation would have taken place, for example, during experiments in Series 4. The very considerable effect at 13 mm. of chlorine caused by adding 318 mm. of hydrogen chloride is accompanied by a reduction of the intensity exponent from its normal figure of 0·9 to 0·72 (Part V, Table II, Expt. 73).

Discussion.

It was shown in Part V that the exponent n, governing the velocity ratio found at two different intensities, decreases as the absolute values of the latter increase, starting at above 0·5 at low intensities and, in the case of experiments with 166 and 450 mm. of chlorine, falling well below this figure at the higher intensities. It is important to determine whether, over a finite intensity range, n remains constant at 0·5 before falling further. If that be the

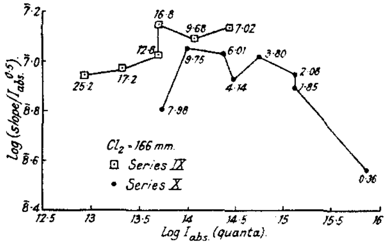
Fig. 1.



case, the graph of log (slope/$I_{abs.}^{0.5}$) against log $I_{abs.}$ should run parallel to the axis of the latter in such an intensity region. Such curves for pressures of 82·6, 166, and 450 mm. of chlorine are reproduced in Figs. 1—3. The figures adjacent to the experimental points are

the γ values as given in Table I. Although the experimental errors are rendered very obvious, there can be no doubt that such an intensity region of constant n does exist in each case, and that it commences at a lower absorbed intensity with a mercury than with a tungsten lamp. In the case of the experiments at 82·6 mm., there is no subsequent falling off in the curve at higher intensities. Similar graphs were made for this pressure of log (slope/$I_{abs.}^{0.3}$) and of log (slope/$I_{abs.}^{0.7}$) against log $I_{abs.}$; in neither case was there any

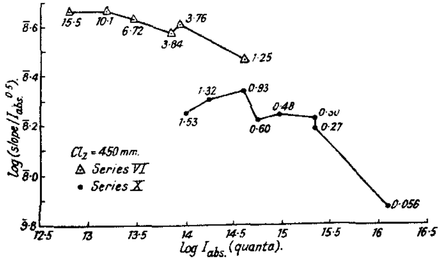
FIG. 2.



tendency towards a portion of the curve running parallel to the intensity axis. In accordance with familiar arguments, we therefore conclude that, when both intensity and also chlorine pressure are sufficiently high, the reaction chains end in the gas phase by the combination of two carrier units, and that, at still higher intensities, a further factor enters which, in some way, masks this process.

In view of the known greater efficiency (a ratio of 10^2—10^3) of H–Cl_2 as compared with Cl–H_2 collisions, and of the great preponderance of chlorine over hydrogen in our experi-

FIG. 3.



ments, there can be no question of hydrogen atoms being involved, and the most obvious suggestion is that chains are ended by a triple collision of the Cl + Cl + M type. This conclusion is, however, forbidden by the fact that, at total pressures of 13—14 mm. (Part V, Table II), the intensity exponent is consistently as low as 0·9, indicating that an important fraction of the chains is broken in the gas phase by the process under discussion, whatever its nature. At such pressures, triple collisions are exceedingly rare events, and a termolecular mechanism could not possibly play an appreciable part in the terminating chains. Some process which does not involve a triple collision is required.

In Part IV (J., 1936, 241), when discussing the fact that, in oxygen-free gases at low total pressures, the value of γ was 30—40% less for ultra-violet than for visible light, we

suggested that the cause was the interaction with chlorine molecules of chlorine atoms of high translatory energy freshly formed by photo-dissociation, the result being the production of Cl_3 radicals at a concentration higher than would correspond to the Cl–Cl_2–Cl_3 equilibrium under the conditions of illumination. These radicals would react less readily with hydrogen molecules than would chlorine atoms, and would also probably be adsorbed more easily on the walls of the reaction cell; hence the reaction chains would become shorter and γ diminish. The assumption that such Cl_3 radicals, no longer selectively formed by *ultra-violet light, but present in equilibrium concentration, play an essential part in the experiments now under discussion, has enabled us to explain satisfactorily, not only the intensity law found in our experiments*, but also the remarkable retarding effect of chlorine. In discussing our results, complex because such wide ranges of chlorine pressure and intensity have been covered, it will be simplest first to deal with those experiments with 82·6 mm. of chlorine in which the $I^{0.5}$ relation was found to hold closely over a considerable range of intensity. Those chosen for review will be X, k, l, m [Fig. 1 and Part V, Table IV (*b*)].

Experiments obeying the $I^{0.5}$ *relation.* The proposed mechanism comprises the following steps:

(1) $Cl_2 + h\nu \longrightarrow 2Cl$	(4) $Cl + Cl_2 \longrightarrow Cl_3$
(2) $Cl + H_2 \longrightarrow HCl + H$	(5) $Cl_3 \longrightarrow Cl + Cl_2$
(3) $H + Cl_2 \longrightarrow HCl + Cl$	(6) $2Cl_3 \longrightarrow 3Cl_2$

It is further assumed that the equilibrium expressed by

$$K = [Cl_3]/[Cl][Cl_2] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

is maintained, or practically so, during the course of the reaction, which signifies that (4) and (5) are relatively so rapid that, when the stationary state has been set up, neither (1) nor (6) can appreciably disturb equilibrium (7). Step (3), for reasons already given, will follow very closely on (2), so that neither [Cl] nor [H] will be thereby affected. Both (4) and (5) can be regarded, if wished, as involving another reaction partner M. According, however, to Rollefson and Eyring (*J. Amer. Chem. Soc.*, 1932, **54**, 170), the quasi-molecule Cl_3 "will have a very long life, as compared with the duration of an ordinary collision." (6), of course, will not require the intervention of a third body in order to produce stable molecules of chlorine. Any reaction such as $Cl_3 + H_2 \longrightarrow Cl_2 + HCl + H$ is neglected. According to Kimball and Eyring (*ibid.*, p. 3876), the efficiency of this collision is 10^{-3}—10^{-4} times that of Cl–H_2 collisions, whilst Rollefson (*ibid.*, 1934, **56**, 579) gives reasons for preferring a ratio of 10^{-1}—10^{-2}. In any case, its introduction would make the velocity equation more complex, whilst altering the nature of the results very slightly.

Working through the above equations in the usual manner due to Bodenstein, we arrive at the result

$$\gamma_{(H_2)} = k_2\,[H_2]/K_7[Cl_2](k_6\,.\,I_{abs.})^{0.5} \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

an expression which reproduces the required first order for hydrogen and the value of 0·5 for *n*, and, in addition, is of the inverse first order for chlorine. From the γ data (quoted on Fig. 1—in part in Table I), the rates of quantum absorption [Fig. 1; Part V, Table IV (*b*)] and the values of k_2 and k_6, K_7 can clearly be found. In all calculations which follow, a temperature of 18° is assumed, and the units of 1 c.c. and 1 second employed. The volume of the reaction cell was 490 c.c., and the quanta absorbed per second are therefore the figures quoted in the table divided by $10^{2.69}$. The coefficients k_2, k_6, etc., have been worked out by the standard methods for 1 mm. pressure of each reactant, and pressures in mm. are introduced into equation (8) instead of concentrations. The value of K_7 which results is therefore K_p of dimensions mm.$^{-1}$. The atomic and molecular diameters (in A.) assumed are: H_2 2·46, Cl_2 4·96, Cl 3·36, Cl_3 6·66. In agreement with Rodebush and Klingelhoefer (*ibid.*, 1933, **55**, 130), we have taken the efficiency of Cl–H_2 collisions as $3{\cdot}5 \times 10^{-5}$ ($E = 5{\cdot}94$ kg.-cals.), and that of Cl_3–Cl_3 collisions as unity. As always, γ values refer to molecules of hydrogen or chlorine at 0·1 mm. of hydrogen, whilst i and ii, here and later, indicate experiments carried out at high and at low intensities respectively.

TABLE IV.

$p_{H_2} = 0·1$; $p_{Cl_2} = 82·6$; $k_2 = 10^{10·44}$; $k_6 = 10^{23·71}$.

Expt.	X, k, i	X, k, ii	X, l, i	X, l, ii	X, m, i	X, m, ii
log $I_{abs.}$	12·96	12·21	12·59	11·83	12·21	11·46
γ	3·18	7·75	6·60	14·3	7·17	13·7
log K	− 2·30	− 2·31	− 2·44	− 2·39	− 2·28	− 2·18

The mean value of K_p is $10^{-2·31}$ or 0·00491 mm.$^{-1}$, whereas the value calculated from the data given by Rollefson and Eyring as the most probable is 0·78 mm.$^{-1}$, *i.e.*, 160 times as high. *Their figure depends on the assumptions that, for reaction (4),* $-\Delta H$ and ΔS are 4·1 kg.-cals. and − 6 respectively. Using the same figure for the entropy change, we find that our value of K corresponds to $-\Delta H = 2·5$ kg.-cals. : K is of course equal to k_4/k_5. The collision number, for pressures of 1 mm., corresponding to k_4, worked out as before, is $10^{23·49}$. The most probable value of E_4, according to Rollefson and Eyring, is 4·5 kg.-cals., and the maximum possible figure 8·6 kg.-cals. The minimum figure consistent with our explanation of the low-pressure wave-length effect is 5·0 kg.-cals. (Part IV; *loc. cit.*, p. 250). With this as a basis, the efficiency of Cl–Cl_2 collisions becomes $10^{-3·75}$ or $1·78 \times 10^{-4}$, and the values of k_4 and of k_5 are $10^{19·74}$ and $10^{22·05}$ respectively. The activation energy of (5) will be 7·5 kg.-cals., as compared with the 8·6 kg.-cals. of Rollefson and Eyring.

Using the data of X, k, ii, where the found value of K coincides with the mean value, and the values of k_4 and k_5 just obtained, we may finally compare the absolute rates (molecules transformed per c.c. per sec.) in the different steps, in order to see whether equilibrium (7) is likely to be maintained on our assumptions. We calculate that, per c.c. and per sec., $10^{16·29}$ chlorine atoms and Cl_3 radicals are formed and disappear in virtue of the opposed reactions (4) and (5), $10^{12·50}$ chlorine atoms are produced by (1) and disappear by (6) after conversion into Cl_3 radicals, and $10^{12·89}$ chlorine atoms react with hydrogen in accordance with (2), and are immediately regenerated by (3). It is plain that neither (1) nor (6) will appreciably disturb equilibrium (7).

The assumption that chain termination is the result of (6) is not the only one which can be made. Thus, the reaction

$$Cl + Cl_3 \longrightarrow 2Cl_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

may be responsible, or (6) and (9) acting in conjunction. The value of k_9, calculated in the usual way, is $10^{23·69}$, very near that of k_6. If (9) only is active, then the equation for γ is identical with (8), except that k_6 must be replaced by $k_9/K_7[Cl_2]$, whilst if both (6) and (9) are operative simultaneously, $k_6 + k_9/K_7[Cl_2]$ must be used. The results of X, k, ii, are then satisfied if K_7 becomes, respectively, $10^{-2·62}$ and $10^{-2·67}$ mm.$^{-1}$, values 2 and 2·3 times lower than the one deduced on the basis of reaction (6). Whilst, however, (6) gives an equation in which γ varies inversely as the first power of the chlorine concentration, the kinetic "order" for chlorine becomes − 0·5 if (9) only is employed, and varies between − 1 and − 0·5 if both reactions are considered. For this reason, we regard (6) as the only significant chain-ending process at the higher chlorine pressures, whilst thinking it quite possible that (9) may play an increasing part as p_{Cl_2} becomes less.

There are, formally, two methods by which our value for K_7 could be brought into line with that calculated by Rollefson and Eyring, *viz.*, by increasing k_2 160-fold, or by decreasing k_6 (or k_9) by the factor $10^{-4·4}$. The accepted figure of $3·5 \times 10^{-5}$ for the efficiency of Cl–H_2 collisions at ordinary temperatures is well established, and to change it to $5·6 \times 10^{-3}$ would be inadmissible. A collision efficiency as low as 4×10^{-5} for (6) would be exceedingly unlikely. It is probable that a steric factor of the order of 10 is involved in Cl_3–Cl_3 collisions, and that our figure for k_6 should be correspondingly reduced, whilst if a higher factor were assumed for Cl–Cl_3 collisions, the relative unimportance of k_9 would receive a ready explanation. Such adjustments would not appreciably affect K, and the discrepancy between our deductions and the calculations of Rollefson and Eyring must remain.

The low n value of 0·9 at total pressures of 13 mm. was mentioned above as the reason for rejecting the step,

$$2Cl + M \longrightarrow Cl_2 + M \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

leading to the very simple expression

$$\gamma_{(H_2)} = k_2[H_2]/(k_{10} \cdot I_{abs.})^{0.5} [M]^{0.5} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (11)$$

Applied to X, k, ii, this necessitates k_{10} (bimolecular collision—consideration of M omitted) having a value of $10^{22.93}$ in the units employed (molecules × c.c.$^{-1}$ × sec.$^{-1}$ × mm.$^{-2}$). On calculation as before, the collision number at 1 mm. pressure is $10^{23.26}$, which means that *27% of all such bimolecular Cl–Cl collisions would have to be effective to account for the experimental results, and this at a total pressure of little over* 0·1 atm., where the proportion of triple collisions is of the order of 10^{-3}—10^{-4}.

Experiments at high chlorine pressures and intensities. Equation (8) demands that γ should be inversely proportional to the chlorine pressure. Table II shows that, at relatively low intensities, this relation is approximately fulfilled as p_{Cl_2} changes from 82·6 to 166 mm., whilst at high intensities, the retarding effect is relatively higher. But on passing from 166 to 450 mm., the inverse power of p_{Cl_2} rises to 2, and, at the same time, and the more so the higher the intensity, n drops below 0·5 [Part V, Table IV, (*c*) and (*d*)]. It will be remembered that the whole volume of the reaction vessel was not insolated, a cylindrical beam of light passing axially down the cell. This suggested that possibly both the phenomena mentioned were due to retarded diffusion of hydrogen from the adjacent dark space into the illuminated zone. Such a view cannot be maintained, however. The actual rates of consumption of hydrogen in these experiments are very low, and the average displacement per second of a hydrogen molecule, calculated by the usual approximate formula, is 1·33 cm. at 450 mm. of chlorine, and 2·19 cm. at 166 mm. We think, nevertheless, that diffusion effects cause the results referred to, not diffusion of hydrogen into the insolated zone from outside, but diffusion of chlorine atoms out of this zone into the rest of the reaction space.

In our treatment of the experiments at 82·6 mm. of chlorine, we assumed that, owing chiefly to convection, the concentration conditions were essentially uniform throughout the whole cell. When, however, we consider the experimental conditions during work at higher chlorine pressures, where γ values are usually much lower, we find that, not only is the sum of the quantities of heat developed by light absorption and by reaction often less than at 82·6 mm. of chlorine, but also, owing to the higher heat capacity of the gases, the resulting temperature rise, and therefore any convection effects, are very much smaller. Thus, rough calculations on the results of the experiments at five different pressures carried out in Series VI (see Table I) indicate that, at a given incident intensity, the relative temperature rises in the illuminated zone are approximately as follows:

450 mm.	166 mm.	82·6 mm.	45·7 mm.	13 mm.
1	8—9	30—35	40	45

This being so, we assume that at these higher pressures, the reaction very largely completes itself inside the light beam, rather than uniformly throughout the whole cell.* If it were to be confined entirely to this insolated zone, then equation (8) would be obeyed, γ being low in consequence of the high concentration of absorbed light. But whilst the data would then necessarily follow the $I^{0.5}$ relation, the experimental figures do not, lower intensity exponents being found.

We think that both the intensity and the enhanced chlorine effects can be explained on the assumption that the reaction under these conditions takes place partly in the light and partly in the dark zone; that in the latter case it is due to chlorine atoms passing out of the beam into the dark space, there finally to disappear, after conversion into Cl_3 radicals, in accordance with (6); and that this movement of chlorine atoms is due at the highest pressures essentially to diffusion, convection playing a subordinate part. Chlorine atoms, rather than Cl_3 radicals, are suggested, as calculations show that the latter, with their slow diffusion rate and short life, cannot be responsible for the effect. Chlorine

* The unusually low value of n found in Expts. 129—131 (Part V, Table III) is due to this same localised action, a consequence of low rate of reaction, heat evolution, and convection.

atoms, on the other hand, diffuse nearly twice as quickly, and, more important, do not disappear as the result of mutual collision. In any case, as soon as chlorine atoms or Cl_3 radicals have escaped from the light beam where they are present in high concentration, their life immediately becomes considerably greater, and increases as they diffuse outwards.

The longer this life, the longer the chain initiated by a chlorine atom. The higher the proportion of chlorine atoms which escape from the insolated zone into the dark space, the higher therefore the average value of γ. This proportion will decrease as the intensity, and hence the rate of production of chlorine atoms, increases; it will, indeed, decrease ever more rapidly after a certain point, a consequence of the finite distance that the atoms must travel before they can escape into the light zone. The result will be that, although in any given small volume element, chains propagate at a rate proportional to p_{Cl} and terminate at a rate proportional to $p^2_{Cl_3}$, corresponding to the $I^{0.5}$ relation, yet at high intensities the fraction of such chains terminated inside the light zone will be greater than at low intensities, and the overall value of n will fall below 0·5. A similar state of affairs was discussed at the end of Part V in connection with the differences between the results given by the mercury and the tungsten lamp. This effect will enter earlier, the higher p_{Cl_2} and hence the slower diffusion. Numerous calculations on these lines, whilst showing that the proposed explanation can account semi-quantitatively for the abnormal intensity exponents observed, have not been successful in leading to an exact treatment of the results, which is not surprising in view of the simplifications necessary.

With regard to the extra inverse power of the chlorine concentration, we assume the volume of the effective reaction zone to be essentially governed by the rate of diffusion of chlorine atoms outward from the central beam. This rate will be inversely proportional to p_{Cl_2}. If it were a question of diffusion in three dimensions from a point source of chlorine atoms, the volume of the reaction zone would be proportional to the cube of the diffusion coefficient, and hence inversely proportional to $p^3_{Cl_2}$. But diffusion along the axis of the cell will have no effect on the reaction volume. We are concerned with diffusion in two dimensions only. Consequently, the reaction volume will vary as $p^{-2}_{Cl_2}$, and the effective absorbed intensity as $p^2_{Cl_2}$. The square root of $I_{abs.}$ appears in the denominator of (8), and hence indirectly the first power of p_{Cl_2}.

The relation between p_{Cl_2} and γ over the range 82·6—166 mm. as set out in Table II shows that, at the latter pressure, the diffusion effect under consideration is only partly operative even at the higher intensities. When p_{Cl_2} is raised to 450 mm., however, the inverse square power of the chlorine indicates that, at this pressure and at the high intensities employed, it is fully active. Series X still being considered (all calculations are referred to experiments in this series in view of the more uniform spatial distribution of the absorbed tungsten-filament radiation), Fig. 3 and Table IV (*d*) of Part V suggest that equation (8) should be applicable to Expt. X, d. If we substitute the experimental data for γ and for $I_{abs.}$, using the value of $10^{-2.31}$ for K, as deduced from the experiments at 82·6 mm. of chlorine, we obtain 66 c.c. for the effective reaction volume, corresponding to a uniform column of 1·8 cm. diameter, which is quite plausible. If now we calculate from this value, by multiplying by $(450/166)^2$, the effective volume of the reaction zone at 166 mm. under limiting diffusion conditions, we get 485 c.c., practically identical with the volume of the reaction vessel. It is, however, doubtful whether such conditions could be realised at 166 mm., owing to convection disturbances. That they are partly operative at higher intensities is shown by the values of the intensity exponent, apart from the data in Table II.

The results of experiments at higher intensities cannot be treated in this way, owing to the fact that the $I^{0.5}$ relation is not obeyed, which makes it impossible to use equation (8).

Experiments at lower chlorine pressures. Effect of added hydrogen chloride. Up to 1·7 mm. of chlorine, n is practically unity, indicating that, oxygen being absent, the reaction is ended by adsorption and recombination of chain carriers on the walls. Hydrogen atoms will play a negligible part, even at the lowest value of p_{Cl_2} used (0·012 mm.). Moreover, on the basis of the figure of $10^{-2.31}$ calculated above for $K = p_{Cl_3}/p_{Cl}p_{Cl_2}$, the ratio $[Cl_3]/[Cl]$ will be very low, even if this equilibrium were completely established, for which the

conditions are not favourable. It is natural, then, to assume that the essential chain-ending reaction will be

$$Cl \xrightarrow{\text{wall}} \tfrac{1}{2}Cl_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (12)$$

the expression for the quantum yield becoming

$$\gamma_{(H_2)} = 2k_2[H_2]/k_{12} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (13)$$

The hydrogen pressure being expressed in mm., and k_2 being as before, k_{12} has the dimensions photon $\times$ c.c.$^{-1}$ $\times$ sec.$^{-1}$ $\times$ mm.$^{-1}$, and is directly calculable from the experimental results. Combining with it the rate of quantum absorption, we can compute the stationary value of p_{Cl}, and hence, by the standard formula, the rate at which chlorine atoms strike the walls of the reaction vessel and the efficiency of these collisions. Bodenstein and Winter (*Sitzungsber. preuss. Akad. Wiss.*, 1936, 1), who did such calculations in connexion with the kinetics of the reaction in oxygen-free gases at atmospheric pressure, recently reported an "accommodation coefficient" as low as $10^{-3\cdot8}$ for the adsorption of chlorine atoms on the walls of the silver reaction vessel used.

TABLE V.

Expt. and series:	52 (8).	46 (8).	51 (8).	43 (8).	45b (8).	25 (4).	29 (4).
p_{Cl_2} (mm.)	0·012	0·012	0·012	1·7	1·7	1·7	1·7
p_{HCl} (mm.)	0·0	6·9	8·6	0·28	6·7	0·26	10·9
γ	270	1960	1720	147	115	11·1	31·4
log K_{12}	16·33	15·47	15·52	16·59	16·70	17·71	17·26
log p_{Cl} (mm.)	− 6·93	− 6·07	− 6·12	− 5·09	− 5·20	− 6·49	− 6·04
log Cl atoms adsorbed by walls *	9·45	9·45	9·45	11·55	11·55	11·27	11·27
log collisions of Cl atoms on walls *	13·35	14·21	14·16	15·19	15·08	13·79	14·24
log collision efficiency	− 3·90	− 4·76	− 4·71	− 3·64	− 3·53	− 2·52	− 2·97

* Per cm.^{2} per second.

In Table V are contained the results of a number of calculations of this kind, for reactions at 0·012 and 1·7 mm. of chlorine, both in the presence and in the absence of added hydrogen chloride. The collision efficiencies are all very low, in agreement with the results of Bodenstein and Winter, as also with earlier direct observations of Rodebush and Klingelhoefer (*loc. cit.*) and of Schwab and Friess (*Z. Elektrochem.*, 1933, **39**, 586). They, moreover, vary over a wide range, in correspondence with observations made by us throughout this work.

According to (13), γ should be independent of p_{Cl_2} in this region, except in so far as this factor may affect k_{12}. When p_{Cl_2} becomes so high that n falls below unity, as is the case at 13 mm. of chlorine, indicating that chains are being ended in the gas phase, a fall off in γ would be expected. Table I shows an example of a rapid decrease in γ as p_{Cl_2} increases from 0·012 to 13 mm., and a number of cases in which γ_{13} definitely exceeds $\gamma_{1\cdot7}$. Examination of these data, as also of a number of unquoted comparisons made early in the work between γ_{13} and $\gamma_{1\cdot7}$, shows plainly (*a*) that if the γ values in a series are generally high (low catalytic action of walls), an increase in p_{Cl_2} decreases γ, whilst if the walls readily adsorb chlorine atoms, γ tends to rise with increase in p_{Cl_2}; (*b*) that, in any given series of experiments, the higher the incident intensity the smaller is the ratio $\gamma_{13} : \gamma_{1\cdot7}$.

We interpret these results as follows. An increase in p_{Cl_2} will reduce the extent of adsorption of chlorine atoms on walls which otherwise would readily catalyse their recombination. If, however, the "accommodation coefficient" of chlorine atoms is already abnormally low, such an effect of increased p_{Cl_2} will be imperceptible. On the other hand, the equilibrium ratio p_{Cl_3}/p_{Cl} is 140 times higher at 1·7 than at 0·012 mm. of chlorine, and the chances that this equilibrium will be approached are much greater. As was assumed in Part IV, Cl_3 radicals will be more readily adsorbed on the walls than chlorine atoms and, with an over-all efficiency of 10^{-3}—10^{-4}, even a small absolute increase in their concentration will mean an appreciable rise in k_{12}, and therefore an appreciable fall in γ. The higher the incident intensity, the higher p_{Cl} and hence p_{Cl_3}, and the more pronounced this effect. At pressures of 13 and 45·7 mm. of chlorine, where n becomes 0·8—0·9, reaction (6)—and

possibly (9)—commences to play a part, and ultimately preponderates. But reaction (12) persists, and only becomes *insignificant* under the conditions of high p_{Cl_2} and high intensity discussed earlier in this paper. In view of the known variability in catalytic properties of the walls, and of the assumed difference in ease of adsorption of Cl and Cl_3, any quantitative treatment of the results in this pressure region, involving both (6) and (12), is impossible.

The effects of added hydrogen chloride, in certain respects, resemble those of chlorine; both acceleration and retardation are observed, the former when the rates of reaction in absence of hydrogen chloride are low, whether owing to reactive vessel walls or to low intensity, and the latter when the velocities are high. In addition, accelerating effects are more marked at low chlorine pressures, and can change to a retardation as p_{Cl_2} increases (*e.g.*, Table V, Expts. 43, 45b, 46, 52). The accelerating effect, as in the case of chlorine, we attribute to the poisoning of the catalysed recombination of chlorine atoms taking place on the walls.* The action of hydrogen chloride in this respect is the stronger, as is revealed, not only by the seven-fold increase in γ shown by Expts. 46 and 51 as compared with 52 (Table III), but also by the results given in Table VI.

TABLE VI.

Expt.	Cl_2 mm.	$+ Cl_2$ mm.	+ HCl mm.	Relative γ.	Expt.	Cl_2 mm.	$+ Cl_2$ mm.	+ HCl mm.	Absolute γ.
13 (3)	1·7	+ 0·0	+ 0·46	1·0 *	25 (4)	1·7	+ 0·0	+ 0·26	11·1
12 (3)	1·7	+ 11·3	+ 0·12	0·75	24 (4)	1·7	+ 11·3	+ 0·0	12·2
22 (3)	1·7	+ 0·0	+ 11·0	1·04	29 (4)	1·7	+ 0·0	+ 10·9	31·4

* Absolute γ *ca.* 50.

The three factors which favour retardation by hydrogen chloride, *viz.*, walls of low catalytic power, relatively high p_{Cl_2}, and relatively high intensity, all imply relatively high values of p_{Cl}, and hence also of p_{Cl_3} and at a given $[Cl_2] : [H_2]$ ratio, of p_H. The first explanation to suggest itself is the possible occurrence of

$$H + HCl \longrightarrow H_2 + Cl \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (14)$$

Everything indicates that k_{14} is of the order, not of k_3, as was deduced by Ritchie and Norrish (*Proc. Roy. Soc.*, 1933, *A*, **140**, 112), but rather of k_2 (Potts and Rollefson, *J. Amer. Chem. Soc.*, 1935, **57**, 1027; Rodebush and Spealman, *ibid.*, p. 1040; experiments of Sommer, quoted by Bodenstein and Winter, *loc. cit.*). With $k_3/k_{14} = 150$, the retarding effect of added hydrogen chloride would be given by the ratio $150[Cl_2] : (150[Cl_2] + [HCl])$, a relation which predicts 2—3% retardation where we observed 20—30%, and this in spite of the assumed superadded accelerating effect. The explanation we favour is that the added hydrogen chloride, by collision, stabilises the newly formed Cl_3 radicals, and that, as already argued, these radicals are adsorbed more easily by the vessel walls than are chlorine atoms. The remarkable decrease in the slope sometimes observed at very low hydrogen pressures in presence of hydrogen chloride (see Part V) is to be ascribed to the same effect. In one case (Table III; Part V, Table II, Expt. 73), where 318 mm. of hydrogen chloride caused a very considerable lowering of γ at $p_{Cl_2} = 13$ mm., this was accompanied by a fall in n to the unusually low figure of 0·72, indicating extensive recombination of Cl_3 radicals in the gas phase. The total heat liberated in the illuminated zone was small, and consequently also the convection effect, and doubtless the main function of the added gas was to restrict diffusion, and thus maintain a relatively high concentration of Cl_3 in and near the centre of the reaction vessel.

Comparison with results of other workers. Any contradiction between our results and those of Bodenstein and Winter is merely apparent. They worked with reaction mixtures in which either hydrogen and chlorine pressures were of the same order, or excess of hydrogen was present. The maximum value of the ratio p_{Cl_2}/p_{H_2} quoted is 1·9 and the minimum as low as 0·02, whilst at 375 mm. of chlorine, their rates of quantum absorption appear to

* This wall poisoning by chlorine and by hydrogen chloride in the present reaction runs quite parallel to the corresponding results in the case of the rate of combination of bromine atoms on the walls of the containing vessel, in absence and in presence of bromine and hydrogen bromide (Schwab, *Z. physikal. Chem.*, 1934, *B*, **27**, 452; Hilferding and Steiner, *ibid.*, 1935, **30**, 399).

have been about 10^9 per c.c. per sec. In our later work, on the other hand, p_{Cl_2}/p_{H_2} varied between limits of about 300 and 30,000, and the rates of quantum absorption, referred to *the whole cell, not merely to the insolated zone, fell between* $10^{10 \cdot 2}$ and $10^{13 \cdot 4}$ per c.c. per *sec. when* p_{Cl_2} was *166 or 450 mm. Both the* p_{Cl_2}/p_{H_2} *ratio and also the stationary chlorine-atom concentration were far higher in our experiments; i.e.*, the conditions were such as to favour

$$(4)\ Cl + Cl_2 \longrightarrow Cl_3\ (k_4 = 10^{19 \cdot 74}\ \text{molecules c.c.}^{-1}\ \text{sec.}^{-1}\ \text{mm.}^{-2})$$

rather than

$$(2)\ Cl + H_2 \longrightarrow HCl + H\ (k_2 = 10^{19 \cdot 46}\ \text{molecules c.c.}^{-1}\ \text{sec.}^{-1}\ \text{mm.}^{-2})$$

and, moreover, to furnish a relatively high stationary Cl_3 concentration, the equilibrium $Cl + Cl_2 \rightleftarrows Cl_3$ being assumed to be set up. In Bodenstein and Winter's experiments, the chances of this last being the case were very slight, and in any case, the resulting Cl_3 concentration would be too low to cause appreciable chain ending by (6) as compared with (12). In the matter of the part played by the vessel walls, we are in agreement with these authors, as also with their brief reference (*loc. cit.*, p. 18) to certain experiments on the effect of hydrogen chloride ("sometimes no change in velocity, sometimes a retardation, and occasionally an acceleration"), except that, under our conditions, an acceleration was observed more often than otherwise.

Potts and Rollefson obtained results at room temperature essentially agreeing with those of Bodenstein, *i.e.*, in accordance with (12), but with evidence of slight systematic retardation by reaction (14). At 167° K., however, their data are expressed by an equation which, rewritten, becomes

$$\gamma = k[H_2]/I_{abs.}^{0 \cdot 5} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (15)$$

formally identical with our expression (8), the first power of the chlorine concentration in the denominator being omitted. The room-temperature measurements involved chlorine and hydrogen pressures varying respectively between about 11—22 mm. and 7—17 mm. Under our conditions, we should have expected for such pressures of chlorine an intensity exponent of about 0·85—0·9, whereas one of unity was found. This is readily explained by the fact that Potts and Rollefson used hydrogen pressures about 100 times as great as those employed by us, with a resulting low value of p_{Cl_2}. In the measurements at 167° K., the ratio p_{H_2}/p_{Cl_2} was $\sim$ 3—4 as compared with $\sim$ 1 at 290° K. Using, as before, 5·94 kg.-cals. and 5·0 kg.-cals. respectively for E_2 and E_4, we calculate, however, that the ratio of the reduction in rate of these two processes on passing from 290° to 167° K. is about 3·3 : 1, and consequently the relative numbers of successful Cl–H_2 and Cl–Cl_2 collisions will be practically the same in the experiments carried out at the two temperatures. On the other hand, K_7 increases as the temperature falls. With $\Delta H = -2 \cdot 5$ kg.-cals. for (4), we calculate that the equilibrium ratio p_{Cl_3}/p_{Cl} at 167° K. will be 24-fold its value at room temperature, and it is to this fact that the change in the value of n must be attributed. The experimental method used by Potts and Rollefson did not allow of any independent variation of p_{Cl_2}; the pressure of chlorine actually used will be included in their k value. Ritchie and Norrish used at any given chlorine pressure (*e.g.*, 44 mm. as in their Tables I and III) much the same total rate of quantum absorption as we did. On the other hand, their reaction cell was of volume 25·4 c.c., as compared with our 491 c.c., and the rate of quantum absorption per unit volume consequently 20 times as great. Their values of n were well below unity,* and, in view of the high hydrogen pressures (*e.g.*, 44 mm.) employed, this can only have been the consequence of the very high stationary chlorine-atom and Cl_3 concentrations resulting from the high rate of light absorption, combined with the presence of cell walls very efficiently poisoned in respect of chlorine-atom recombination. The effect of p_{Cl_2} on γ over the range 12—90 mm. was much as observed by us. They also found a marked and progressive retardation when p_{HCl} was increased from 12·5 to 317 mm. in a

* According to them, 0·6; but whilst this fits their results at 67 mm. of chlorine, the data at 44 mm. are better expressed by a figure of 0·7.

mixture containing 44 mm. each of hydrogen and of chlorine, and attributed it to the occurrence of reaction (14). They did no measurements on the effect of adding smaller quantities of hydrogen chloride. Whilst we cannot agree with this interpretation of their results, it should be remarked that we observed similar effects in a few isolated experiments (Table III), and have ascribed them to enhanced concentrations of Cl_3.

SUMMARY.

(1) Quantum yields varying between 0·05 and 2000 are calculated for the experiments recorded in Parts V and VI. Depending on the conditions, they either pass through a maximum at some intermediate chlorine pressure, or, in a few cases, decrease continuously as the chlorine pressure increases. At high intensities and pressures of chlorine, they vary under the conditions of experiment in accordance with the inverse square power of the chlorine pressure.

(2) Experiments on the effect of added hydrogen chloride are tabulated and discussed.

(3) Suggestions are put forward to explain the experimental results. Reaction chains are ended by the disappearance of chlorine atoms and of Cl_3 radicals, both on the walls and, without triple collisions, in the gas phase. The rôles played by non-uniform illumination, convection, and diffusion are estimated.

(4) The results are compatible with those obtained by other workers on the same reaction.

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398. *The Photochemical Union of Hydrogen and Chlorine. Part VII. The Effect of Water Vapour on the Reaction at Low Pressures.*

By H. C. CRAGGS and A. J. ALLMAND.

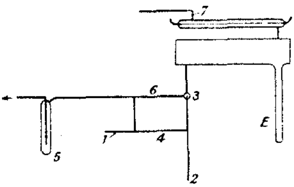
Intensive drying of a low-pressure mixture of hydrogen and chlorine does not inhibit the reaction in light. On the contrary, the addition of small quantities of water vapour to the dried gases retarded the reaction somewhat under the conditions of experiment.

WHEN our experiments were commenced, it was generally believed, on the authority of Coehn and Jung (*Z. physikal. Chem.*, 1924, **110**, 705), that visible light was without action on a hydrogen–chlorine mixture if the aqueous vapour pressure were reduced to 10^{-7} mm., whilst at 10^{-5} mm. ready reaction took place. On the other hand, in the experiments of Bateman and Craggs (*Trans. Faraday Soc.*, 1931, **27**, 445), where the chlorine pressures, as in the present work, were controlled by suitable low-temperature refrigerants, normal reaction was observed. The refrigerant presumably also determined the pressure of water vapour in the reaction space at a value not greater than the sublimation pressure of ice at the temperature concerned, *i.e.*, at about 10^{-6} mm., 10^{-8} mm., and 10^{-9} mm. when melting carbon disulphide, methyl*cyclo*hexane and allyl chloride respectively were used. Quite apart, then, from the probability that the actual water vapour pressures would be less than those given, owing to the formation of chlorine hydrate, the results of Bateman and Craggs, amply confirmed in our own experiments, directly contradicted those of Coehn and Jung. However, although the walls of the apparatus were baked out in the preliminary evacuation, there remained the faint possibility of their slowly giving off water during the insolation, and of this distilling through the reaction space into the cooled limb. Such distillation would, of course, tend to be rapid at the low prevailing total pressures.

EXPERIMENTAL.

In order to eliminate this possibility, the matter was subjected to a more rigorous test. For this purpose, the palladium tube (7 in the figure) for the admission of hydrogen was sealed

on to the Pirani gauge, thus allowing the whole apparatus (of glass) to be evacuated with a stream of pure dry hydrogen passing through it. Such treatment is particularly effective in removing traces of adsorbed vapour from solid surfaces. The whole reaction space, including the gauge, was then baked out at 200° in an air-oven of simple construction, projecting parts being dealt with by resistance-wire electric heaters. During this treatment, hydrogen gas was passed through continually. After the temperature had been lowered and the gas stream discontinued, the gauge zero was determined, purified chlorine admitted in the usual way, and liquid air placed around *E*. With the exception of this cooled limb (from now onwards always immersed in either liquid air or a low-temperature refrigerant), the whole apparatus was again heated to 200°, and hydrogen passed through for 8 hours, at a mean pressure of about 1 mm. The reaction vessel was then sealed off, and the system allowed to cool. Hydrogen was removed by heating the palladium tube until the pressure had fallen within the range of the gauge, the liquid air on *E* replaced by melting methyl*cyclo*hexane, and insolation commenced in the ordinary way, a metal-filament lamp being used with interposition of a 5-mm. glass plate. Great care was taken when changing the temperature of *E* that it should not rise above the m. p. of methyl*cyclo*hexane. Reaction took place freely at an estimated aqueous vapour pressure not exceeding 10^{-8} mm.



An experiment was also done in which the rates of reaction in a given gas mixture, after addition of a known partial pressure of water, were compared with the rate in the "dry" gas. As in the last experiment, the reaction vessel was used with the palladium tube sealed on to the Pirani gauge (see fig.). The water was produced in a side tube 1 situated between the main apparatus and the chlorine supply, and containing 0·0021 g. of calcined cupric oxide. This, after evacuation and admission of hydrogen, was heated, and the liberated water frozen out by liquid air in another side tube 2, which was connected with the main apparatus through an internal capillary seal, 3, which could be broken by a magnetically operated, glass-covered, iron plunger. The copper oxide tube was then sealed off from the water supply at 4 after the excess of hydrogen had been pumped out. In carrying out the experiment, the apparatus was baked out as before in a hydrogen stream, and the pumps shut off. Hydrogen was admitted, the copper oxide reduced, and the water frozen out and isolated as described. Chlorine was purified as usual and collected in 5, which was immersed in liquid air. The main apparatus was again baked out, and allowed to cool in a hydrogen stream. Excess of the latter was pumped off, and the pumps shut off from the reaction vessel. The liquid air on 5 was replaced by melting carbon disulphide (p_{Cl_2} = 1·7 mm.), and, after a suitable interval, the apparatus sealed off at 6. The result was a baked-out reaction system containing 1·7 mm. of chlorine, but with no excess condensed out in *E*, into which hydrogen could be admitted at will, and water vapour up to a pressure of about 0·7 mm. (calculated from the volume of the system and the weight of cupric oxide taken), the actual figure depending on the refrigerant used on *E*. With liquid air on *E*, the gauge zero was tested, hydrogen admitted, and the palladium tube sealed off at 7.

The cell was then insolated under four different sets of conditions, *viz.*: (*a*) *E* in melting ethyl acetate (189·6° K.) and no water in apparatus; (*b*) water admitted by breaking inside seal (pressures of hydrogen and of chlorine fell slightly on account of increase in dead space)—*E* at 189·6° K., $p_{H_2O} = 2 \times 10^{-4}$ mm.; (*c*) *E* in melting carbon disulphide (161·4° K.)—$p_{H_2O} = 10^{-6}$ mm.; (*d*) *E* at room temperature—p_{H_2O} about 0·7 mm. The results are shown in the table.

Expt.	p_{H_2} (mm.).	Time (mins.).	Average slope.	Average p_{Cl_2}.	Slope/p_{Cl_2}.
(*a*)	0·598	0	0·216	1·62	0·13
	0·554	15			
	0·496	39			
	0·444	60			
(*b*)	0·433	0	0·125	1·41	0·089
	0·424	10			
	0·377	48			
(*c*)	0·377	0	0·168	1·37	0·12
	0·357	14			
(*d*)	0·357	0	0·133	1·42	0·093
	0·347	15			

The observed rate of reaction fell off appreciably when water vapour was admitted in (*b*), although its pressure can have been only 2×10^{-4} mm., apart from the formation of chlorine

hydrate. It rose again, (*c*), when the water vapour was frozen out at a lower temperature, and decreased when p_{H_2O} was allowed to rise to its maximum figure. In column 5, it is assumed that the water condensed out in *E* during (*b*) and (*c*) as chlorine decahydrate, and 0·07 mm. has consequently been subtracted from what otherwise would have been the average chlorine pressure. The last column gives corrected relative slopes, the rate of reaction being assumed proportional to p_{Cl_2}.

The results show clearly that, under our conditions, water did not accelerate, but rather retarded, the action. At the low total pressures of the experiments (1·7—2·5 mm.), this effect is presumably due to the formation of an adsorbed film of water on the surface of the reaction vessel which accelerates the catalytic action of the walls on chlorine atoms. Such a result is quite different from what is observed when hydrogen atoms are involved. On the other hand, Rodebush and Klingelhoefer (*J. Amer. Chem. Soc.*, 1933, **55**, 130) have made observations which accord with ours. The main result of our work, *i.e.*, the absence of any retardation due to the intense drying of the gases, has already been briefly reported (*Nature*, 1932, **130**, 927) and is in complete agreement with the conclusions of Bernreuther and Bodenstein (*Sitzungsber. preuss. Akad. Wiss.*, 1933, 333), of Rodebush and Klingelhoefer (*loc. cit.*), and of Rollefson and Potts (*J. Amer. Chem. Soc.*, 1933, **55**, 860).

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399. *Preparation of* m-*Dimethylaminobenzaldehyde. Part I.*

By A. C. BOTTOMLEY, WESLEY COCKER, and (MISS) PHYLLIS NANNEY.

m-*Dimethylaminobenzaldehyde* has been conveniently prepared from *m*-aminobenzaldehyde by methylation of its acetal and distillation of the quaternary iodide.

p-DIMETHYLAMINOBENZALDEHYDE is readily prepared by a variety of technical processes (D.R.-PP. 105,103, 105,105, etc.) and the *o*-isomer is also easily obtained in 60% yield by the methylation of anthranil (Bamberger, *Ber.*, 1904, **37**, 973). The direct methylation of *o*-aminobenzaldehyde is, however, not as satisfactory (Bamberger, *loc. cit.*, p. 989). Attempts to methylate the supposed *m*-aminobenzaldehyde (anhydro-compound, C_7H_5N) by direct methods are futile and the materials remain unchanged, but the methylation of *m*-aminobenzaldehydediethylacetal by means of methyl iodide proceeds very smoothly. The acetalisation of the anhydro-compound is effected by means of a mixture of 5% alcoholic hydrogen chloride and ethyl orthoformate, the latter ensuring no loss of acetal by the presence of moisture in the reactants, since it is more readily decomposed by acid than the acetal (compare Claisen, *Ber.*, 1893, **26**, 2731; 1896, **29**, 1005, 2931; 1900, **33**, 3778; 1903, **36**, 3664; 1907, **40**, 3903; *Annalen*, 1894, **281**, 312; 1896, **291**, 43; 1897, **297**, 3). The yields of acetal by this method have been as high as 85%, which compare very favourably with the yields obtained by Haworth and Lapworth (J., 1922, **121**, 76) by the reduction of *m*-nitrobenzaldehydediethylacetal with sodium sulphide. During the methylation process deacetalisation takes place and the final product is the *quaternary salt* of the free aldehyde. This is the more interesting since deacetalisation in alkali is unusual. It is probable that it takes place before quaternary salt formation, as theoretically the acetal of the quaternary salt [$CH(OEt)_2 \cdot C_6H_4 \cdot NMe_3I$] should be as stable as that of *m*-nitrobenzaldehyde. The quaternary salt of the free aldehyde is, however, smoothly decomposed on distillation under reduced pressure into *m*-dimethylaminobenzaldehyde and a little of its hydriodide, the overall yields being about 35% on the anhydro-*m*-aminobenzaldehyde.

EXPERIMENTAL.

m-*Aminobenzaldehydediethylacetal.*—A mixture of commercial *m*-aminobenzaldehyde (25 g.), 5% alcoholic hydrogen chloride (175 g.), and ethyl orthoformate (75 g.) was kept in a stoppered

flask for 12 hours at room temperature, sodium ethoxide (prepared from 8 g. of sodium and 175 c.c. of alcohol) then added to the well-agitated mixture to remove the excess of hydrogen chloride, and the whole diluted with water (4—5 vols.). The precipitated pale yellow oil was extracted with ether in a continuous apparatus, dried (anhydrous potassium carbonate), and recovered (36 g.) on the water-bath at 60°; as a rule it was directly used for methylation experiments as described below. For analysis a sample was fractionally distilled in a vacuum, the portion, b. p. 137—139°/5 mm., being almost pure acetal (Found: C, 67·5; H, 8·7; N, 7·5. Calc. for $C_{11}H_{17}O_2N$: C, 67·7; H, 8·7; N, 7·2%). Its ready conversion into the free amino-aldehyde by warming with a trace of mineral acid establishes its identity (compare Haworth and Lapworth, *loc. cit.*). Although distillation of the acetal is described, this procedure is not to be recommended, as much decomposition takes place during the process and even during the removal of ether from an ethereal solution at temperatures above about 60°.

Methylation. The crude acetal (36 g.), suspended in 10% aqueous sodium carbonate (200 c.c.), was heated under reflux on the steam-bath with methyl iodide (91 g.; 1·16 mols.), added at intervals during 24 hours. The cooled mixture was diluted with water (200 c.c.) and extracted (continuous) with ether to remove unchanged acetal and methyl iodide. The liquid, containing deposited quaternary salt, was boiled with animal charcoal, filtered hot, and concentrated. Successive crops of quaternary salt were collected, each being washed with a little ice-cold water and dried; yield, 46·5 g. (66% on *m*-aminobenzaldehyde used); m. p. 180—200° (decomp.). Recrystallisation from water gave little improvement in m. p. (Found: C, 41·5; H, 5·1. $C_{10}H_{14}ONI$ requires C, 41·2; H, 4·8%). The crystals were poorly defined, but are probably flat, transparent prisms. Aqueous solutions immediately give silver iodide with silver nitrate. The view that the quaternary salt is that of the free aldehyde is supported by the facts that gentle boiling with hydriodic acid under reflux yielded no ethyl iodide and gentle heating with nitric acid or chromic acid and sulphuric acid yielded neither ethyl nitrite nor acetaldehyde.

m-*Dimethylaminobenzaldehyde.*—The quaternary iodide (20 g.) was heated under reduced pressure (10—15 mm.) in a Claisen flask immersed in an oil-bath at 150—160° and finally at 190—200° until distillation ceased. The yellow distillate was filtered from *m*-dimethylaminobenzaldehyde hydriodide (about 6% of the total weight) and consisted of almost pure m-*dimethylaminobenzaldehyde* (6·6 g.; 46% yield calc. on *m*-aminobenzaldehyde). On fractionation under reduced pressure it distilled at 137·5—138°/9 mm., giving a pale yellow oil with a strong basic odour, readily soluble in mineral acids, alcohol, ether and benzene (Found: C, 72·7; H, 7·5. $C_9H_{11}ON$ requires C, 72·5; H, 7·4%). The *oxime*,* prepared by standard methods in 97—99% yield, was deposited in long, transparent, colourless prisms from aqueous alcohol, m. p. 75—76° (Found: C, 65·7; H, 7·6. $C_9H_{12}ON_2$ requires C, 65·9; H, 7·3%). The *semicarbazone* was deposited in thin, shiny, colourless plates, m. p. 218—222° (slow heating) or 228—229° (instantaneous) (Found: C, 58·5; H, 6·8. $C_{10}H_{14}ON_4$ requires C, 58·2; H, 6·8%). The methiodide, obtained by gently warming the aldehyde with methyl iodide for a few minutes, was a pale yellow solid, m. p. 185—186° (decomp.), similar in all respects to the methiodide prepared as above (Found by titration: I, 45·7. Calc. for $C_{10}H_{14}ONI$: I, 43·6%). The *picrate*, prepared in alcohol, formed flat rectangular plates, soluble in hot benzene and hot water; m. p. 147—147·5° (Found: N, 14·8. $C_{15}H_{14}O_8N_4$ requires N, 14·8%).

The authors express their thanks to Professor A. Lapworth, F.R.S., for his interest during the investigation.

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* Dr. Shoppee (J., 1932, 702) obtained the oxime from aldehyde prepared according to the method described above and recorded m. p. 75·5° (private communication).

Sixth Report of the Committee on Atomic Weights of the International Union of Chemistry.

By G. P. Baxter (Chairman), O. Hönigschmid, and P. Lebeau.

The following report of the Committee covers the twelve-month period, September 30, 1934, to September 30, 1935.*

Three changes have been made in the table of atomic weights. Those of tantalum and radium have been changed from 181·4 and 225·97 to 180·88 and 226·05, respectively. Protoactinium, with atomic weight 231, has been added to the table.

Carbon.—For some time it has seemed probable that the International value for the atomic weight of carbon, 12·00, is too low (Reports of this Committee for 1933 and 1934). Many recent determinations of densities and compressibilities of gaseous hydrocarbons and oxides of carbon have yielded values higher than this. Furthermore, the isotopic weight of ^{12}C from mass spectrographic results appears to be slightly higher than 12·00 on the chemical scale (Aston, *Proc. Roy. Soc.*, 1935, *A*, **149**, 400; *Nature*, 1935, **135**, 541) and allowance for 1/106 (Jenkins and Ornstein, *Proc. Acad. Sci. Amsterdam*, **35**, 1212) or 1/410 (Aston, *loc. cit.*) of ^{13}C raises the average value for the mixture of isotopes by about 0·01 unit.

Pending the completion of chemical determinations of the atomic weight of carbon now under way, no change has been made in the value in the International Table, although the value 12·01 appears nearer the true value than 12·00.

Potassium.—Johnson (*J. Physical Chem.*, 1935, **39**, 781) has determined the ratio KCl : Ag. Five samples of potassium chloride were prepared from the sources and by the operations indicated below :

1. Norwegian potassium oxalate. Six crystallisations as oxalate, one as chloride and fusion.
2. German potassium nitrate. Ten crystallisations as nitrate, three precipitations as chloride with hydrogen chloride with intermediate fusion and crystallisation from water.
3. German potassium chlorate. Ten crystallisations as chlorate, and decomposition to chloride.
4. German potassium chloride. One crystallisation from water, two precipitations with hydrogen chloride with intermediate fusion and crystallisation from water, one crystallisation from constant-boiling hydrochloric acid, one from water and fusion.
5. Searles Lake, California, U.S.A., potassium chloride. One crystallisation from dilute ammonia, two crystallisations from water, one from normal hydrochloric acid (made from the same sample), eight crystallisations from water and fusion.

The Atomic Weight of Potassium.

Sample of KCl.	Wt. of KCl.	Wt. of Ag.	Ratio KCl : Ag.	At. wt. K.
1	7·174405	10·38101	0·691109	39·100
2	7·159125	10·35886	0·691111	39·100
3	7·139503	10·33051	0·691108	39·100
4	7·110874	10·28910	0·691107	39·100
5	7·119655	10·30174	0·691112	39·100
1	7·113533	10·29294	0·691108	39·100
2	7·124221	10·30839	0·691109	39·100
3	7·241729	10·47841	0·691110	39·100
4	7·128585	10·31474	0·691107	39·100
5	7·163709	10·36550	0·691111	39·100
1	7·132066	10·31981	0·691104	39·099
2	7·151197	10·34747	0·691106	39·100
3	7·230660	10·46250	0·691103	39·099
4	7·212326	10·43594	0·691105	39·099
5	7·102363	10·27681	0·691106	39·100
			Average 0·691108	39·100

* Authors of papers bearing on the subject are requested to send copies to each of the three members of the Committee at the earliest possible moment : Prof. G. P. Baxter, Coolidge Laboratory, Harvard University, Cambridge, Mass., U.S.A.; Prof. O. Hönigschmid, Sofienstrasse 9/2, Munich, Germany; Prof. P. Lebeau, Faculté de Pharmacie, 4, Avenue de l'Observatoire, Paris (6e), France.

All five samples were further crystallised three times from water, filtered through platinum sponge, and again crystallised.

The salt was prepared for weighing by fusion in nitrogen (in a Pt–Rh boat), and after being dissolved to make a 0·2N-solution was added dropwise to a 0·2N-solution of an equivalent amount of pure silver. In Analyses 3, 12, 13, 14, and 15 both solutions were added dropwise to 200 ml. of water. After standing 13 to 50 days at room temperature the end-point of the titration was found, after cooling to 0°, by the "standard solution" method (Johnson) and potentiometrically.

The atomic weight of potassium thus found is slightly higher than recent values found by others from the same ratio, and that employed in the International Table.

Chromium.—Nunez (*Anal. Fis. Quim.*, 1935, **33**, 533) has redetermined the atomic weight of chromium through the ratios of chromyl chloride to silver and silver chloride. Dry potassium dichromate which had been six times recrystallised from slightly acid solution was mixed with dry sodium chloride which had been six times precipitated with hydrogen chloride. Upon the mixture, contained in an exhausted glass system, was dropped concentrated sulphuric acid, and the resulting chromyl chloride was collected over metallic silver. The product was then subjected to several fractional distillations in exhausted glass systems, in the first two of which the chromyl chloride stood over silver for 24-hour periods. The final product was collected in sealed glass bulbs.

A preliminary preparation (Series I) was made in a glass system containing greased joints. In preparing material for Series II and III only fused connections were employed. Series II and III represent more and less volatile portions of the same sample.

During the handling of the chromyl chloride care was taken so far as possible to avoid exposure to light, in order to avoid decomposition, since the substance is photochemically sensitive, especially to light of short wave-length.

After being weighed, the bulbs containing the chromyl chloride were broken under water and the chloride was precipitated with solutions of nearly equivalent quantities of pure silver. The end-point was determined nephelometrically, and finally the silver chloride was washed, collected, dried, and weighed. Dissolved silver chloride was estimated nephelometrically.

Weights are corrected to vacuum.

The Atomic Weight of Chromium.

Series.	Sample.	Wt. of CrO_2Cl_2.	Wt. of Ag.	Ratio $CrO_2Cl_2 : 2Ag$.	At. wt. Cr.	Wt. of AgCl.	Ratio $CrO_2Cl_2 : 2AgCl$.	At. wt. Cr.
I	1	2·23946	3·11873	0·718068	52·016	4·14375	0·540443	52·017
	2	3·40565	4·74299	0·718039	52·010	6·30183	0·540422	52·011
			Average	0·718054	52·013		0·540432	52·014
II	1	3·95716	5·51087	0·718064	52·015	7·32206	0·540443	52·017
	2	5·20776	7·25239	0·718075	52·018	9·63597	0·540450	52·019
	3	3·81350	5·31090	0·718052	52·013	7·05634	0·540436	52·015
	4	4·00910	5·58329	0·718053	52·013	7·41855	0·540416	52·009
	5	2·99479	4·17077	0·718042	52·011	5·54165	0·540415	52·009
			Average	0·718057	52·014		0·540432	52·014
III	6	3·78022	5·26473	0·718027	52·008	6·99504	0·540414	52·009
	7	2·94949	4·10753	0·718069	52·017	5·45773	0·540424	52·012
	8	1·41900	1·97620	0·718045	52·011	2·62570	0·540427	52·012
			Average	0·718047	52·012		0·540422	52·011
			Average of all	0·718053	52·013		0·540429	52·013

The result, 52·013, confirms the current value in the International Table.

Arsenic.—Baxter and Frizzell (*J. Amer. Chem. Soc.*, 1935, **57**, 851) have determined the ratio of arsenic trichloride to iodine, by hydrolysing weighed quantities of arsenic trichloride with disodium phosphate and allowing the arsenious acid to react with weighed very nearly equivalent quantities of iodine in nearly neutral solution. A slight deficiency of one or the other was then made up with dilute solutions of arsenious acid or iodine.

Arsenic trichloride was purified by extensive fractionation in exhausted systems and collected in weighed glass capsules. Iodine was purified by three distillations from tassium iodide made from iodine of the same degree of purity as that to be distilled

(Samples I and II). Sample III resulted from thermal decomposition of very pure iodine pentoxide in an earlier investigation of Baxter and Butler on the atomic weights of iodine. All three samples were sublimed over hot platinum in a current of air. In Series 1 the iodine was weighed in stoppered weighing tubes. In Series 2 and 3 it was weighed in exhausted sealed glass bulbs. The hydrolysis of the arsenic trichloride and the reaction of the arsenious acid with iodine were carried out without contact with oxygen by working in exhausted vessels up to the final determination of the end-point. Fractions of arsenic trichloride are numbered in the order of decreasing volatility. Weights are corrected to vacuum.

The value 126·917 is used for the atomic weight of iodine. In this paper the erroneous value 126·916 is employed.

The Atomic Weight of Arsenic.

Fraction of $AsCl_3$.	Sample of I_2.	Wt. of $AsCl_3$.	Wt. of I_2.	Ratio $AsCl_3 : I_2$.	At. wt. As.
		Series 1.			
3	I	10·33337	14·46807	0·714219	74·922
10	III	12·03069	16·84522	0·714190	74·915
32	III	11·90242	16·66431	0·714246	74·929
31	III	11·76237	16·46851	0·714234	74·926
11	III	11·50761	16·11185	0·714233	74·926
12	III	10·86983	15·21915	0·714221	74·923
13	III	10·43957	14·61741	0·714187	74·914
14	III	10·52815	14·74051	0·714232	74·925
16	II	9·23191	12·92578	0·714225	74·924
15	II	9·75285	13·65529	0·714218	74·922
			Average	0·714221	74·923
		Series 2.			
4	I	11·07602	15·50784	0·714221	74·923
5	II	11·02523	15·43720	0·714199	74·917
6	II	10·81172	15·13922	0·714153	74·905
9	III	11·03085	15·44504	0·714200	74·917
7	III	11·41153	15·97940	0·714140	74·902
			Average	0·714183	74·913
		Series 3.			
33	III	14·50315	20·30806	0·714157	74·906
34	III	16·22008	22·71162	0·714175	74·911
30	III	9·63062	13·48470	0·714189	74·914
17	III	10·11654	14·16485	0·714200	74·917
29	III	10·05286	14·07583	0·714193	74·915
28	III	10·60621	14·85068	0·714190	74·915
19	III	11·13389	15·58919	0·714206	74·919
27	III	10·93869	15·31583	0·714208	74·919
20	III	9·78401	13·69959	0·714183	74·913
26	III	9·85690	13·80122	0·714205	74·919
25	III	9·62562	13·47741	0·714204	74·918
21	II	10·24867	14·34997	0·714195	74·916
22	III	9·97953	13·97324	0·714189	74·914
			Average	0·714192	74·915
			Average of all	0·714200	74·917

The result supports the present International value.

TELLURIUM.—Hönigschmid and Baudrexler (*Z. anorg. Chem.*, 1935, **223**, 91) have compared tellurium tetrachloride with silver. Tellurium was dissolved in nitric acid and the basic nitrate was four times recrystallised from nitric acid. Ignition to dioxide followed. After solution in hydrochloric acid the metal was precipitated with hydrazine, and after being dried was distilled in a current of hydrogen (I). A second sample which was used in an earlier investigation on the tetrabromide was similarly purified, except that the final distillation was in vacuum (II). In a spectrographic examination Gerlach found both samples to be free from impurities.

To prepare the tetrachloride, tellurium metal was heated in oxygen-free chlorine in a quartz apparatus until the mixture of di- and tetra-chloride formed at first had been completely converted into tetrachloride. It was then twice sublimed in a current of

chlorine and hydrogen chloride and collected in a weighed quartz tube. After fusion in chlorine the product was allowed to solidify and cool in nitrogen, and was transferred to a weighing-bottle in dry air. This material was used in the first series of analyses.

Other samples of the tetrachloride, prepared in an identical fashion, were sublimed in exhausted glass apparatus and sealed in glass bulbs for weighing. Here slight dissociation of the tetrachloride into the darker dichloride was sometimes observed. The analyses in the second series were made only with fractions which showed no trace of darkening.

For analysis the tellurium tetrachloride was dissolved in tartaric acid and then compared with weighed equivalent amounts of pure silver in the usual way, and the silver chloride was collected and weighed. Weights are corrected to vacuum.

The Atomic Weight of Tellurium.

Sample of Te.	Wt. of $TeCl_3$.	Wt. of Ag.	Ratio $TeCl_4 : 4Ag$.	At. wt. Te.	Wt. of AgCl.	Ratio $TeCl_4 : 4AgCl$.	At. wt. Te.
			$TeCl_4$ sublimed in chlorine and hydrogen chloride.				
II	3·10877	4·97861	0·624425	127·62			
II	3·10067	4·96557	0·624434	127·63			
II	2·76664	4·43026	0·624487	127·65	5·88640	0·470006	127·65
II	3·22268	5·16097	0·624433	127·63	6·85689	0·469929	127·64
II	2·83816	4·54547	0·624393	127·61	6·03937	0·469943	127·61
II	2·48858	3·98535	0·624432	127·63	5·29502	0·469985	127·64
II	2·90220	4·64760	0·624451	127·64	6·17487	0·470002	127·65
II	2·46428	3·94633	0·624449	127·63	5·24358	0·469961	127·62
II	2·28970	3·66727	0·624361	127·60	4·87216	0·469956	127·62
II	2·87152	4·59861	0·624432	127·63	6·11069	0·469918	127·60
II	2·41697	3·87036	0·624482	127·65	5·14279	0·469973	127·63
II	2·07278	3·31955	0·624416	127·62	4·41041	0·469975	127·63
		Average	0·624433	127·63		0·469965	127·63
			$TeCl_4$ sublimed in vacuum.				
I	3·28709	5·26438	0·624402	127·61	6·99440	0·469960	127·62
I	2·55532	4·09223	0·624432	127·63			
I	4·47487	7·16715	0·624358	127·60	9·52250	0·469926	127·60
I	6·26285	10·02985	0·624421	127·62	13·32623	0·469964	127·64
I	3·10159	4·96705	0·624433	127·63	6·59955	0·469970	127·63
II	2·31719	3·71078	0·624448	127·63			
		Average	0·624416	127·62		0·469955	127·62

The average value 127·63 is only slightly higher than that recently found by Hönigschmid, Sachtleben, and Wintersberger from analyses of tellurium tetrabromide and the synthesis of silver telluride, 127·61.

TERBIUM.—Marsh (J., 1934, 1972; 1935, 772) purified terbium material, containing chiefly gadolinium, dysprosium, and terbium, by fractionation of the dimethylphosphates until the arc lines of gadolinium in the tail fractions and the absorption bands of dysprosium in the head fractions could not be detected. Terbium oxalate was precipitated with oxalic acid, washed, and air dried at 30°. Weighed portions of oxalate were ignited in silica crucibles first in air at 1000°, then in hydrogen at 700—800°, and, after rapid cooling by quenching with water, were weighed. Other weighed portions of oxalate were dissolved in dilute sulphuric acid containing manganous sulphate, and then were titrated with standard permanganate. Weights are corrected to vacuum.

The Atomic Weight of Terbium.

Wt. of $Tb_2(C_2O_4)_3$.	Wt. of Tb_2O_3.	% of Tb_2O_3.	Wt. of $Tb_2(C_2O_4)_3$.	Wt. of C_2O_3.	% of C_2O_3.
0·8046	0·38337	47·655	0·34336	0·09662	28·139
1·16364	0·55446	47·649	0·32038	0·09010	28·119
1·33993	0·63838	47·643	0·32307	0·09091	28·139
1·27706	0·60848	47·647	0·56839	0·15977	28·110
1·14461	0·54333	47·644	0·57361	0·16147	28·149
	Average	47·648	0·58153	0·16365	28·141
			0·62028	0·17465	28·157
				Average	28·136

The average atomic weight of terbium calculated from the two percentages is 158·89, which is lower than that found by Urbain from the ratio of octahydrated sulphate to sulphate, 159·2, but agrees with Aston's finding that terbium is a simple element of atomic weight 158·91.

EUROPIUM.—Meyers and Hopkins (*J. Amer. Chem. Soc.*, 1935, **57**, 241) have compared europium chloride with silver. Starting with material consisting chiefly of samarium, europium, and gadolinium, fractional crystallisation as double magnesium nitrates was first carried out with the addition of bismuth to split samarium and europium. Fractional crystallisation of the europium and gadolinium fractions as simple nitrates followed, with bismuth as separating element. After removing most of the samarium in this way, further fractionation as double magnesium nitrates, as simple nitrates, and again as double magnesium nitrates was carried out. Of the final twelve fractions, Nos. 8, 9, and 10 gave no spectroscopic evidence of impurity.

After removal of bismuth, each of these fractions was purified by alternate precipitation of oxalate and hydroxide, and the final oxalate was ignited to oxide.

Chloride was prepared by dissolving the oxide in a weighed quartz flask and, after evaporation, dehydrating the chloride slowly in a current of dry hydrogen chloride, at gradually increasing temperatures until fusion took place. The weighed fused salt was compared with pure silver in the conventional way. Weights are corrected to vacuum.

The Atomic Weight of Europium.

Fraction.	Wt. of $EuCl_3$.	Wt. of Ag.	Ratio $EuCl_3$: 3Ag.	At. wt. Eu.
8	1·15506	1·44544	0·79911	152·25
9	0·43279	0·54140	0·79939	152·33
10	0·60180	0·75291	0·79930	152·31
9	1·10986	1·38862	0·79924	152·29
8	1·00560	1·25820	0·79924	152·29
10	0·52157	0·65262	0·79919	152·27
8	0·90408	1·13104	0·79933	152·32
9	0·33150	0·41472	0·79930	152·31
10	0·57944	0·72498	0·79925	152·29
8	0·91942	1·15035	0·79925	152·29
			Average 0·79926	152·30

The final result is considerably higher than both the present International value and that recently found by Aston, 151·90.

TANTALUM.—Hönigschmid and Schlee (*Z. anorg. Chem.*, 1934, **221**, 129) have compared tantalum pentabromide with silver. Potassium tantalum fluoride was six times recrystallised from hydrofluoric acid, and then was converted into tantalic acid with hot concentrated sulphuric acid. Potassium sulphate was removed by washing and the dried acid was ignited at 1000°. *X*-Ray analysis by Prandtl and von Hevesy failed to reveal niobium and zirconium, but 0·1% of thorium remained. The latter was reduced to 0·01% by fusing with soda and extracting the residue, with rejection of the insoluble portion (I).

Material recovered from the earlier analyses constituted a second sample (II).

The pentabromide was prepared in two ways. The first consisted in heating a mixture of the tantalic oxide with carbon in a current of nitrogen and bromine. The resulting pentabromide was then fractionated in an exhausted system and collected in sealed glass bulbs for weighing.

In the second method the oxide was first converted into sulphide by heating it to 1000° in a current of hydrogen sulphide and carbon disulphide, and the sulphide was then changed to bromide in a stream of nitrogen and bromine. Fractional distillation in a current of nitrogen and bromine eventually eliminated all sulphur bromide, and the product was distilled into exhausted glass bulbs, which were sealed by fusion.

The weighed bulbs were broken under cold oxalic acid, and the tantalic acid which separated was dissolved by warming for some hours. After cooling, the clear solution was filtered and the glass collected and weighed. Comparison with silver in the usual way followed. Weights are corrected to vacuum.

The Atomic Weight of Tantalum.

Sample of $TaBr_5$.	Wt. of $TaBr_5$.	Wt. of Ag.	Ratio $TaBr_5 : 5Ag$.	At. wt. Ta.
I	4·01046	3·72677	1·07612	180·879
I	3·36860	3·13031	1·07612	180·879
I	2·31963	2·15539	1·07620	180·922
I	2·98695	2·77560	1·07615	180·895
I	5·97976	5·55678	1·07612	180·879
I	2·69510	2·50447	1·07611	180·876
I	2·58878	2·40553	1·07618	180·911
I	2·15134	1·99927	1·07606	180·847
II	3·91760	3·64051	1·07611	180·876
II	4·92095	4·57277	1·07614	180·890
II	3·43463	3·19157	1·07616	180·899
II	7·95901	7·39614	1·07610	180·870
II	4·48505	4·16776	1·07613	180·884
II	4·54602	4·22440	1·07613	180·887
			Average 1·07613	180·884

The average result agrees closely with Aston's finding that tantalum is a simple element of atomic weight 180·89, and seems to warrant a change in the value for this element in the International Table.

Radiogenic Lead.—Baxter and Alter (*J. Amer. Chem. Soc.*, 1935, **57**, 467) have determined the atomic weights of several radiogenic leads. Lead chloride from each specimen was purified by precipitation as sulphide, crystallisation of the nitrate and chloride, and sublimation of the chloride in hydrogen chloride. The ratio of lead chloride to silver was found in the conventional way by the equal opalescence method. Weights are corrected to vacuum.

The Atomic Weight of Lead.

Source.	Fusion atmosphere.	Wt. of $PbCl_2$.	Wt. of Ag.	Ratio $PbCl_2 : 2Ag$.	At. wt. Pb.
Uraninite, Besner Mine, Parry Sound, Ontario, Canada.	N_2 + HCl	2·82198	2·19830	1·28371	206·059
	N_2 + 10% HCl	1·17902	0·91849	1·28365	206·046
				Average 1·28368	206·052
Pitchblende, Great Bear Lake, N.W.T., Canada.	N_2 + HCl	2·17006	1·69051	1·28367	206·051
	N_2 + HCl	3·44166	2·68097	1·28374	206·065
				Average 1·28370	206·058
Cyrtolite, Hybla, Ontario, Canada.	HCl	0·77361	0·60233	1·28436	206·20
	N_2 + 50% HCl	0·47163	0·36722	1·28433	206·19
				Average 1·28434	206·20
Cyrtolite II, Bedford, New York, U.S.A.	N_2 + 10% HCl	2·99554	2·33341	1·28376	206·070
	N_2 + 10% HCl	3·20665	2·49788	1·28375	206·067
	HCl	1·06532	0·82984	1·28377	206·071
	N_2 + 50% HCl	3·28903	2·56206	1·28374	206·067
	N_2 + 10% HCl	3·31553	2·58255	1·28382	206·083
				Average 1·28377	206·072
Cyrtolite I, Bedford.	N_2 + 50% HCl	0·48244	0·37596	1·28322	205·954
Galena, Yancey County, North Carolina, U.S.A.	N_2 + 10% HCl	3·45151	2·67758	1·28904	207·209
	N_2 + 10% HCl	4·29642	3·33305	1·28904	207·208
				Average 1·28904	207·209
Curite, Katanga, Africa.	N_2 + 50% HCl	2·99570	2·33388	1·28357	206·029
	N_2 + 50% HCl	2·01485	1·56973	1·28357	206·028
	HCl	3·01913	2·35212	1·28358	206·031
	N_2 + 10% HCl	2·93470	2·28639	1·28355	206·025
	N_2 + 50% HCl	2·00228	1·55997	1·28354	206·022
				Average 1·28356	206·027

The value for Great Bear Lake material agrees with that found by Marble; that for Bedford cyrtolite I with that found earlier by Baxter and Alter; that for curite lead with the value found simultaneously by Hönigschmid with a portion of the same material.

Radium.—Hönigschmid and Sachtleben (*Z. anorg. Chem.*, 1934, **221**, 65) have redetermined the atomic weight of radium through the ratio $RaBr_2 : RaCl_2$. Five grams of radium bromide, lent by the Union Minière du Haut-Katanga, were available. Initially this contained 98·83 atomic % of radium and 1·17 of barium. After ten

recrystallisations of the chloride by precipitation with hydrogen chloride in quartz, the atomic % of barium had dropped to 0·3. Fifteen additional similar crystallisations yielded material of atomic weight 226·005. A third series of crystallisations from constant-boiling hydrochloric acid raised the atomic weight to 226·05. Ten more crystallisations from constant-boiling hydrochloric acid followed. The final material was examined spectroscopically by Gerlach, who estimates the residual barium at not more than 0·002—0·003 atomic %, which would lower the atomic weight of radium by 0·002—0·003 unit.

Radium bromide was prepared from the chloride by repeated evaporation with a large excess of hydrobromic acid in quartz. After transference to a weighed quartz boat it was dehydrated in a current of nitrogen and hydrogen bromide at gradually increasing temperatures to 750°, and the dried salt was transferred to a weighing-bottle in air. The weighed salt was then heated in a current of chlorine and hydrogen chloride, at first at 300°, finally at 750°, and when the chlorine and hydrogen chloride had been displaced by nitrogen at 300°, the chloride was transferred to the weighing-bottle in dry air. Constancy in weight was readily secured.

Although neither the radium bromide nor the radium chloride was fused before being weighed, very similar experiments in which pure barium bromide was converted to chloride yielded a normal atomic weight, so that it is evident that errors from moisture retained by the radium bromide, incomplete conversion, adsorbed air and temperature of the radium salts were either negligible or compensatory.

After the first six experiments had been completed, it was discovered that radium salts, when placed on the balance, owing to heat evolution at first slowly lost in weight, coming to constancy after a period of about an hour. The weights given in the last two analyses in the table represent values obtained after constancy had been reached. For the first six analyses the weights given represent the minimum values observed where the weighings were repeated.

All weights are corrected to vacuum.

The Atomic Weight of Radium.

Crystal Series.	Wt. of $RaBr_2$.	Wt. of $RaCl_2$.	Ratio $RaBr_2 : RaCl_2$.	At. wt. Ra.
III	2·18675	1·68286	1·299424	226·049
III	3·49878	2·69256	1·299425	226·048
IV	3·46519	2·66677	1·299396	226·077
IV	3·41017	2·62432	1·299449	226·025
IV	3·43249	2·64150	1·299447	226·026
IV	3·40754	2·62239	1·299402	226·070
		Average	1·299424	226·049
IV	3·42566	2·63631	1·299415	226·059
IV	2·35813	1·81475	1·299424	226·049
		Average	1·299420	226·054
		Average of all	1·299423	226·050

The Atomic Weight of Barium.

Wt. of $BaBr_2$.	Wt. of $BaCl_2$.	Ratio $BaBr_2 : BaCl_2$.	At. wt. Ba.
4·89362	3·42946	1·426936	137·356
4·71132	3·30176	1·426912	137·368
3·76377	2·63768	1·426924	137·362
5·04872	3·53818	1·426926	137·361
	Average	1·426925	137·361

The atomic weight of radium thus found is 0·08 higher than the value found by Hönigschmid some years ago with much smaller quantities of material. The new value, 226·05, has been adopted for the International Table.

PROTOACTINIUM.—von Grosse (*Proc. Roy. Soc.*, 1935, *A*, 150, 363), working with material isolated by von Grosse and Agruss, has determined the ratio $2K_2PaF_7 : Pa_2O_5$. After two precipitations with hydrogen peroxide from dilute sulphuric acid solution, the preparation showed no evidence of impurity when examined in an *X*-ray spectrograph. The double fluoride was prepared by dissolving protoactinium oxide in hydrofluoric acid

and adding the necessary quantity of potassium fluoride. The resulting crystals were twice recrystallised from hydrofluoric acid.

After being dried at 20° in vacuum over phosphorus pentoxide, the double fluoride was converted into sulphates by evaporation with an excess of sulphuric acid, and then the protoactinium was precipitated as hydroxide with ammonia, collected, ignited eventually to 800°, and weighed. Weights are corrected to vacuum.

The Atomic Weight of Protoactinium.

Wt. of K_2PaF_7.	Wt. of Pa_2O_5.	Ratio $2K_2PaF_7 : Pa_2O_5$.	At. wt. Pa.
0·091907	0·056274	1·6332	230·4
0·070047	0·042913	1·6323	230·8
		Average 1·6328	230·6

The result seems to be in accord with the expectation that protoactinium has the atomic weight 231.

Aston (*Proc. Roy. Soc.*, 1935, *A*, **149**, 396), by determination of packing fractions and abundance ratios with the mass spectrograph, has obtained the following atomic weights.

Carbon	12·0080	Gallium	69·71
Calcium	40·076	Zirconium	91·24
Titanium	47·91	Silver	107·87
Iron	*55·84*	*Cadmium*	*112·2*
Nickel	58·68	Indium	114·80
Hafnium	178·4		

The only serious discrepancy between these values and the International values is with cadmium.

Thorium and rhodium were found to be probably simple.

By comparison of doublets, Aston (*Nature*, 1935, **135**, 541) has obtained new values for several light atoms, although these are still regarded as provisional.

	$^{16}O = 16·0000$.	$O = 16·0000$.
H	1·0081	1·0079
D	2·0148	2·0143
He	4·0041	4·0031
^{12}C	12·0048	12·0018

If the abundance ratio of D is 1/5000 and that of ^{13}C is 1/100, the atomic weights of hydrogen and carbon become 1·0081 and 12·012.

Seventh Report of the Committee on Atomic Weights of the International Union of Chemistry.

By G. P. Baxter (Chairman), O. Hönigschmid and P. Lebeau.

The following report of the Committee covers the twelve-month period, September 30, *1935*, to September *30*, *1936*.*

The following changes in the table of atomic weights have been made :

Carbon, from 12·00 to 12·01.
Rubidium, from 85·44 to 85·48.
Gadolinium, from 157·3 to 156·9.
Lead, from 207·22 to 207·21.
Uranium, from 238·14 to 238·07.

Oxygen.—Dole (*J. Amer. Chem. Soc.*, 1935, **57**, 2731; *J. Chem. Physics*, 1936, **4**, 268) reports a difference in isotopic composition between the oxygen of the air and that of the water of Lake Michigan, U.S.A., corresponding to 0·00008 atomic weight unit, and

* Authors of papers bearing on the subject are requested to send copies to each of the three members of the Committee at the earliest possible moment : Prof. G. P. Baxter, Coolidge Laboratory, Harvard University, Cambridge, Mass., U.S.A.; Prof. O. Hönigschmid, Sofienstrasse 9/2, Munich, Germany; Prof. P. Lebeau, Faculté de Pharmacie, 4, Avenue de l'Observatoire, Paris (6e), France.

advocates some single isotope such as protium as atomic weight standard. Since analytical accuracy under the most favourable conditions does not surpass 0·001%, and since the determination of atomic weights by chemical methods, no matter what standard is used, must in most cases involve reference to oxygen more or less directly, the Committee sees no reason to change the position taken in its Second Report (*J. Amer. Chem. Soc.*, 1932, **54**, 1269), that no advantage is to be gained by any change of standard at the present time.

HYDROGEN.—Although no change in the atomic weight of hydrogen is made in this year's table, it seems increasingly probable, from mass spectrographic measurements (Aston, *Nature*, 1935, **135**, 541; 1936, **137**, 357), that the atomic weight of hydrogen is 0·0002—0·0003 higher than the current value. As pointed out by Moles (*Anal. Fis. Quim.*, 1935, **33**, 721), chemical determinations have ordinarily been made with electrolytic hydrogen, which, owing to isotopic separation, has a less than normal proportion of deuterium.

CARBON.—Toral and Moles (*Bol. Acad. Cienc. exactas, fis. y nat., Madrid*, 1936, **2**, No. 4, 4) have determined the density of carbon dioxide, made by pyrolysis of sodium bicarbonate, with the following average results. Individual results are not given:

1 atmosphere	1·97701
1/2 ,, ...	1·97014

Limiting density is then 1·96327, and the atomic weight of carbon 12·006 if gram-molecular volume is taken as 22·4146. Using their own value for the limiting density of oxygen, Toral and Moles obtain the value 12·007 for carbon.

Baxter and Hale (*J. Amer. Chem. Soc.*, 1936, **58**, 510) have determined the atomic weight of carbon by combustion of hydrocarbons. A weighed amount of hydrocarbon was burned in pure oxygen and both the carbon dioxide and the water formed were collected and weighed. From the weight of water the weight of hydrogen was calculated and subtracted from the weight of hydrocarbon to find the weight of carbon, from which, with the weight of carbon dioxide, the ratio of carbon to oxygen may be calculated.

Hydrocarbons were purified by chemical treatment, by crystallisation from hydrocarbon solvents and distillation or sublimation.

Combustion was effected by slowly evaporating weighed amounts of hydrocarbon into a stream of an excess of oxygen which passed over platinum catalysts in a quartz tube, first at 650°, but eventually at 800°. A short section of copper oxide provided for a possible deficiency of oxygen. Water was collected largely by condensation, but partly by phosphorus pentoxide. Carbon dioxide was collected in ascarite (sodium hydroxide), and escape of water from the carbon dioxide absorber was prevented by phosphorus pentoxide. Vacuum corrections are applied.

Results with pyrene were inconsistent and differed from those with other hydrocarbons.

The Atomic Weight of Carbon.

Wt. of Sample.	Wt. of H_2O.	Wt. of H.	Wt. of C.	Wt. of CO_2.	Wt. of O.	$C : O_2$.	At. wt. C.
			Chrysene.				
2·78044	1·31209	0·14680	2·63364	9·65247	7·01883	0·375225	12·007 (2)
2·69258	1·27609	0·14277	2·54981	9·34368	6·79387	0·375310	12·009 (9)
2·97782	1·41063	0·15782	2·82000	10·33447	7·51447	0·375276	12·008 (8)
2·99649	1·41913	0·15877	2·83772	10·39870	7·56098	0·375311	12·010 (0)
					Average	0·375281	12·009 (0)
			Triphenylbenzene.				
3·00012	1·59012	0·17790	2·82222	10·34136	7·51914	0·375338	12·010 (8)
2·99773	1·58730	0·17759	2·82014	10·33463	7·51449	0·375294	12·009 (4)
2·99639	1·58592	0·17743	2·81896	10·33026	7·51130	0·375296	12·009 (5)
					Average	0·375309	12·009 (9)
			Anthracene.				
2·99484	1·51453	0·16945	2·82539	10·35398	7·52859	0·375288	12·009 (2)
2·04930	1·03682	0·11600	1·93330	7·08554	5·15224	0·375235	12·007 (5)
					Average	0·375262	12·008 (4)
						Average of all	12·009 (1)

This result is in accord with recent gas density and mass spectrographic evidence that *the atomic weight of carbon is not far from 12·01. Accordingly the International value has been altered to this figure.*

Batuecas (Bol. Univ. Santiago, Oct.–Dec. 1935) recalculates his data on the densities of several gases, and finds values for carbon from 11·999 to 12·007, and for nitrogen 14·011 and 14·009.

NEON.—Jungbluth-Ficht and Hoeppener (*Ber.*, 1935, **68**, 2389), starting with neon containing 18% of helium, fractionated this gas by adsorption on active charcoal at low temperature. The products of the last three fractionations gave the following densities (volume of globe = 300 ml., g = 980·616).

A	0·8988
B	0·89949
C	0·89990

The density of the purest fraction (C) corresponds to the atomic weight of neon in current use.

POTASSIUM.—Brewer (*J. Amer. Chem. Soc.*, 1936, **58**, 365, 370) has measured the abundance ratio $^{39}K/^{41}K$ in potassium from various sources. With minerals the ratio varied from 14·11 to 14·32 (except for one sample which gave 14·6). With plant ash a larger variation was found, from 12·63 (kelp) to 14·6 (potato sprouts). In sea water from different localities the ratio was constant at 14·20. The abundance ratio 14·20, with the packing fraction $- 7·0 \times 10^{-4}$ and the conversion factor 1·00027, gives 39·094 for the atomic weight of potassium. With the average abundance ratio from minerals, 14·25, the atomic weight is 39·093. The abundance ratio corresponding to the atomic weight 39·096 is 13·93.

GALLIUM.—Lundell and Hoffman (*Bur. Stand. J. Res.*, 1935, **15**, 409) have determined the ratio of gallium to gallium oxide. Gallium of 99·999% purity was prepared by a combination of wet methods, electrolysis, and fractional crystallisation of the metal (Hoffman, *Bur. Standards J. Res.*, 1934, **13**, 665). By chemical and optical examination the crystals were found to be free from oxide film. In one set of experiments weighed crystals were dissolved in a mixture of nitric, hydrochloric, and sulphuric acids and after removal of nitric and hydrochloric acids, gallium hydroxide was precipitated with ammonia. The hydroxide was collected and ignited at 1200—1300° to constant weight (I). In another the gallium sulphate was evaporated to dryness and ignited at 1200—1300° (II). In a third, after solution in mixed nitric and hydrochloric acids, the hydrochloric acid was eliminated by evaporation with nitric acid and the solution of gallium nitrate evaporated to dryness and the residue ignited at 1200—1300° (III). Oxide samples prepared by the three methods were found to be free from occluded gases. Weights are corrected to the vacuum standard.

The Atomic Weight of Gallium.

Method.	Wt. of Ga.	Wt. of Ga_2O_3.	2Ga : Ga_2O_3.	At. wt. Ga.
I	0·86526	1·16307	0·74394	69·730
I	1·25888	1·69205	0·74400	69·750
I	1·23368	1·65815	0·74401	69·753
I	3·45532	4·64464	0·74394	69·727
I	2·97452	3·99838	0·74393	69·725
		Average	0·74396	69·737
II	1·15767	1·55604	0·74398	69·745
II	1·53230	2·05967	0·74395	69·733
II	2·48716	3·34320	0·74395	69·730
II	3·09080	4·15443	0·74398	69·741
		Average	0·74397	69·737
III	0·78420	1·05411	0·74395	69·730
III	0·80495	1·08196	0·74397	69·740
		Average	0·74396	69·735
		Average of all	0·74396	69·737

The difference between the average value for gallium and that found earlier by Richards and Craig, through the analysis of $GaCl_3$, 69·72, warrants further investigation.

GERMANIUM.—Hönigschmid, Wintersberger, and Wittner (*Z. anorg. Chem.*, 1935, **225**, 81) have determined the ratio of germanium tetrabromide to silver and silver bromide. The tetrabromide was synthesised from spectroscopically pure germanium and pure bromine and was fractionally distilled in exhausted glass systems. Glass bulbs were partially filled with material at various stages of the fractionation. After being weighed, the bulbs were broken under sodium hydroxide and the glass was collected for weighing. The solution was then acidified and compared with silver in the usual way. Finally the silver bromide was collected. Weights are corrected to vacuum. Fractions are numbered in the order of decreasing volatility.

The Atomic Weight of Germanium.

Fraction.	Wt. of $GeBr_4$.	Wt. of Ag.	$GeBr_4$: 4Ag.	At. wt. Ge.	Wt. of AgBr.	$GeBr_4$: 4AgBr.	At. wt. Ge.
	3·57997	3·93852	0·908963	72·572	6·85620	0·522151	72·567
4	7·58115	8·33982	0·909030	72·601	14·51750	0·522208	72·610
6	4·90761	5·39888	0·909005	72·590	9·39827	0·522182	72·591
7	6·13136	6·74501	0·909022	72·597	11·74160	0·522191	72·598
9	4·57465	5·03256	0·909011	72·592	8·76096	0·522163	72·577
11	8·62179	9·48497	0·908995	72·586	16·51123	0·522177	72·587
12	6·31559	6·94772	0·909016	72·595	12·09440	0·522191	72·598
13	6·80706	7·48879	0·908967	72·573	13·03664	0·522148	72·565
14	5·46488	6·01211	0·908979	72·579	10·46570	0·522171	72·582
15	6·03550	6·63974	0·908996	72·586	11·55892	0·522151	72·567
	60·01956	66·02812	0·909000	72·588	114·94142	0·522175	72·586
	Total		Average		Total	Average	

Hönigschmid and Wintersberger (*Z. anorg. Chem.*, 1936, **227**, 17) have determined the ratio of germanium tetrachloride to silver and silver chloride. Germanium was recovered from the tetrabromide analyses by precipitation as hydroxide or sulphide, and after conversion into oxide was reduced in hydrogen. The tetrachloride, which was synthesised from the metal and chlorine prepared from pyrolusite and hydrochloric acid, was fractionally distilled in exhausted systems and collected in sealed glass bulbs. These were analysed as described above. Weights are corrected to vacuum.

The Atomic Weight of Germanium.

Fraction.	Wt. of $GeCl_4$.	Wt. of Ag.	$GeCl_4$: 4Ag.	At. wt. Ge.	Wt. of AgCl.	$GeCl_4$: 4AgCl.	At. wt. Ge.
1	3·10145	6·24157	0·496902	72·595			
2	2·21830	4·46415	0·496914	72·600			
4	3·04473	6·12798	0·496857	72·576	8·14193	0·373957	72·579
6	3·45885	6·96104	0·496887	72·589			
7	3·06428	6·16679	0·496900	72·594			
8	3·47933	7·00214	0·496895	72·592			
10	2·75854	5·55169	0·496883	72·587	7·37629	0·373974	72·589
5	4·20694	8·57525	0·496888	72·589			
3	2·95678	5·95028	0·496914	72·601	7·90580	0·374001	72·605
	28·34320	57·04089	0·496893	72·591	23·42402	0·373977	72·591
	Total		Average		Total	Average	

The average result, 72·59, is 0·01 unit lower than the International value, which depends upon the work of Baxter and Cooper.

RUBIDIUM.—Archibald, Hooley, and Phillips (*J. Amer. Chem. Soc.*, 1936, **58**, 70) have redetermined the ratio RbCl : Ag. Rubidium dichloroiodide was fractionally crystallised ten times from dilute hydrochloric acid. Conversion through the sulphate into the hydroxide by means of barium hydroxide was followed by neutralisation with tartaric acid and five recrystallisations of the acid tartrate. After conversion of the tartrate into carbonate by ignition, the chloride was formed and recrystallised three times. Spectrographic analysis yielded no evidence of the presence of other alkalis.

Rubidium chloride was prepared for weighing by fusion in nitrogen, and was compared with pure silver by the "standard solution" method of Johnson. Weights are corrected to vacuum.

The Atomic Weight of Rubidium.

Wt. of RbCl.	Wt. of Ag.	RbCl : Ag.	At. wt. Rb.
2·41226	2·15167	1·12111	85·488
2·77942	2·47848	1·12142	85·519
2·90458	2·59105	1·12100	85·476
2·51028	2·23897	1·12118	85·495
3·04508	2·71636	1·12101	85·478
2·25778	2·01411	1·12098	85·474
2·44580	2·18166	1·12107	85·484
2·59528	2·31509	1·12103	85·479
Average of last six analyses		1·12104	85·481

Archibald and Hooley (*J. Amer. Chem. Soc.*, 1936, **58**, 618) have continued the foregoing investigation by the determination of the ratios RbBr : Ag : AgBr. Rubidium nitrate resulting from the rubidium chloride analyses was freed from silver and converted into acid tartrate which was four times crystallised. Conversion into bromide followed. The first fraction of crystals formed Sample I. The remainder was converted into tribromide and twice recrystallised. The crystals after conversion into bromide formed Sample II, the mother-liquors Sample III. Comparison of weighed amounts of rubidium bromide with silver was followed by gravimetric determination of the silver bromide formed. Weights are corrected to vacuum.

The Atomic Weight of Rubidium.

Sample.	Wt. of RbBr.	Wt. of Ag.	RbBr : Ag.	At. wt. Rb.	Wt. of AgBr.	RbBr : AgBr.	At. wt. Rb.
I	3·67283	2·39554	1·53320	85·485			
I	3·27067	2·13320	1·53322	85·488			
II	4·04039	2·63537	1·53314	85·479			
II	3·20309	2·08916	1·53320	85·485			
II	4·00547	2·61245	1·53322	85·488			
II	6·66951	4·35022	1·53314	85·480	7·57272	0·880728	85·481
II	4·69377	3·06150	1·53316	85·481	5·32945	0·880723	85·480
II	3·33389	2·17458	1·53312	85·477			
III	3·62456	2·36409	1·53317	85·483	4·11561	0·880686	85·473
		Average	1·53315	85·483		0·880712	85·478

The average value from the three ratios, 85·48, is 0·04 unit higher than that found by Archibald over thirty years ago, and has been adopted for the table.

SILVER.—Hönigschmid and Schlee (*Z. angew. Chem.*, 1936, **49**, 464) have determined the ratio of silver nitrate to silver chloride in the dry way. Silver nitrate which had been prepared from the purest silver was crystallised from nitric acid, and after being dried in pure air at 150° was fused at 220°. Conversion of the weighed nitrate into chloride was effected, first at 150° in hydrogen chloride diluted with nitrogen, later at higher temperatures in more concentrated hydrogen chloride, until finally the fusion temperature was passed. No loss of silver salt occurred during the conversion. Weights are corrected to vacuum.

The Ratio of Silver Nitrate to Silver Chloride.

Wt. of $AgNO_3$.	Wt. of AgCl.	$AgNO_3$: AgCl.
6·60708	5·57445	1·185244
6·25586	5·27812	1·185244
6·53756	5·51582	1·185238
6·42000	5·41662	1·185241
6·19269	5·22483	1·185242
7·48847	6·31810	1·185241
6·58954	5·55968	1·185237
6·76512	5·70780	1·185241
Total 52·85632	44·59542	Average 1·185241

This experimental value affords close confirmation of International atomic weights which give, as the value to be expected, 1·185235.

CADMIUM.—Hönigschmid and Schlee (*Z. anorg. Chem.*, 1936, **227**, 184) have analysed cadmium chloride and bromide. Cadmium metal was fractionally distilled in vacuum until spectroscopic examination (Gerlach) showed no impurities. Cadmium chloride

was prepared by solution of the metal in nitric acid and displacement of the nitric acid by hydrochloric acid. After crystallisation the salt was dehydrated and twice sublimed in hydrogen chloride (Sample I). A second sample was made by heating the metal in dry hydrogen chloride, and twice subliming the product (Sample II). Preparatory to weighing, the chloride was fused in nitrogen in a quartz system, since chlorine and hydrogen chloride are retained if the operation is conducted in these gases.

Cadmium bromide was synthesised by heating the metal in a current of nitrogen and bromine in a quartz apparatus, and was twice resublimed in nitrogen and bromine before the final fusion in nitrogen. Analysis by comparison with silver followed the conventional lines. Weights are corrected to vacuum.

The Atomic Weight of Cadmium.

Sample.	Wt. of $CdCl_2$.	Wt. of Ag.	$CdCl_2$: 2Ag.	At. wt. Cd.
I	3·57277	4·20504	0·849640	112·404
I	4·04302	4·75840	0·849659	112·408
I	3·77238	4·43989	0·849656	112·407
I	4·07495	4·79598	0·849659	112·409
		Average	0·849654	112·407
II	4·23323	4·98215	0·849679	112·413
II	4·42435	5·20722	0·849657	112·408
II	4·87970	5·74305	0·849670	112·411
II	3·43664	4·04470	0·849665	112·410
		Average	0·849668	112·411
		Average of all	0·849661	112·409

Wt. of $CdBr_2$.	Wt. of Ag.	$CdBr_2$: 2Ag.	At. wt. Cd.	Wt. of AgBr.	$CdBr_2$: 2AgBr.	At. wt. Cd.
4·13490	3·27717	1·26173	112·399	5·70479	0·724812	112·402
4·07813	3·23214	1·26174	112·402	5·62629	0·724835	112·410
4·09476	3·24530	1·26175	112·403	5·64920	0·724839	112·411
5·28536	4·18885	1·26177	112·407			
6·12808	4·85675	1·26177	112·407	8·45436	0·724842	112·413
	Average	1·26175	112·404		0·724832	112·409

The average of all the individual values, 112·41, is identical with the present International value, and is 0·2 unit higher than Aston's most recent mass spectroscopic determination, 112·2.

GADOLINIUM.—Naeser and Hopkins (*J. Amer. Chem. Soc.*, 1935, **57**, 2183) have determined the ratio of gadolinium chloride to silver. Samarium–europium–gadolinium material was fractionally crystallised as double magnesium nitrates with and without bismuth as "separating element," and then as simple nitrates with bismuth nitrate as separator. Bismuth was eventually removed as sulphide, and the gadolinium was five times alternately precipitated as hydroxide and oxalate. Of the eight final fractions, 7—14, the first six showed only gadolinium in their arc spectra.

Gadolinium chloride was prepared for weighing by evaporating to dryness a solution of the salt in a weighed quartz flask and cautious expulsion of the crystal water wholly by efflorescence, all in a current of hydrogen chloride. Fusion in hydrogen chloride

The Atomic Weight of Gadolinium.

Fraction.	Wt. of $GdCl_3$.	Wt. of Ag.	$GdCl_3$: 3Ag.	At. wt. Gd.
7	0·38265	0·47047	0·81333	156·86
7	0·82483	1·01416	0·81331	156·85
8	1·56656	1·92608	0·81334	156·86
8	0·63482	0·78060	0·81325	156·82
9	0·68899	0·84716	0·81330	156·85
9	2·27153	2·79249	0·81344	156·89
10	1·89197	2·32637	0·81329	156·84
10	1·41902	1·74486	0·81326	156·83
11	1·23485	1·51829	0·81332	156·85
11	1·61684	1·98796	0·81332	156·85
12	1·72986	2·12689	0·81333	156·86
12	2·48952	3·06091	0·81333	156·85
		Average	0·81332	156·85

followed. Comparison with silver followed conventional lines, by the equal opalescence method. Weights are corrected to vacuum.

Since this result is in accord with Aston's recent finding, the value 156·9 has been adopted for the International table.

ERBIUM.—Hönigschmid (*Naturwiss.*, 1936, **24**, 619) has redetermined, by analysis of the chloride, the atomic weight of an erbium preparation containing 0·37 atomic % of yttrium and 0·42% of thulium. The value found was 166·96, which, when corrected for yttrium and thulium, becomes 167·24. The material used earlier by Hönigschmid and Kapfenberger, which gave the value 165·2, was found to contain 2·9 atomic % of yttrium, 2·9% of holmium, 3·9% of thulium and 2·7% of ytterbium. Correction for these impurities raises the observed value to 167·35. The discrepancy between the results of Hönigschmid and Kapfenberger, and of Aston, 167·15, is thus largely removed.

However, the Committee feel that it is advisable to defer any change in the value for erbium in the table until the details of Hönigschmid's work are available.

TANTALUM.—Hönigschmid and Schlee (*Z. anorg. Chem.*, 1935, **225**, 64) have continued their work on the atomic weight of tantalum by analysis of tantalum pentachloride. The purification of tantalum material consisted in recrystallisation of the double potassium fluoride, conversion into tantalic acid by evaporation with sulphuric acid, extraction of potassium salt with hot water, and ignition at 1000°. At this stage, niobium, thorium, and zirconium had been eliminated, but a trace of iron remained. This was removed by fusion with sodium hydroxide and precipitation of iron as sulphide. Precipitation of tantalic acid with sulphurous acid and ignition followed.

The pentachloride was prepared by first converting the oxide into sulphide by heating in a current of hydrogen sulphide and carbon disulphide, and then heating the sulphide in chlorine. Removal of sulphur chloride was effected by distillation in a current of chlorine and by heating in a high vacuum. The product was distilled into small glass bulbs for weighing.

The weighed bulbs were broken under alcohol, and after dilution with water the glass was collected and weighed. Precipitation of tantalic acid with ammonia followed, and after addition of a slight excess of nitric acid the solution was compared with weighed quantities of pure silver. Weights are corrected to vacuum.

The Atomic Weight of Tantalum.

Wt. of $TaCl_5$.	Wt. of Ag.	$TaCl_5$: 5Ag.	At. wt. Ta.
2·59060	3·90135	0·664026	180·891
2·86797	4·31891	0·664049	180·903
2·43804	3·67183	0·663985	180·869
1·58970	2·39423	0·663971	180·861
3·13325	4·71853	0·664030	180·893
4·25695	6·41098	0·664009	180·883
Total 16·87651	25·41583	Average 0·664016	180·885

The average result agrees exactly with that previously found by the authors from the analysis of the pentabromide.

LEAD.—Hecht and Kroupa (*Z. anorg. Chem.*, 1936, **226**, 248) have determined the atomic weights of several radiogenic leads. Lead chloride from each specimen was purified by crystallisation as nitrate, conversion into sulphate and into carbonate, recrystallisation as nitrate and as chloride, and sublimation of the chloride in hydrogen chloride. The ratios of lead chloride to silver and silver chloride were found in the conventional way. Weights are corrected to vacuum.

The value for Great Bear Lake material is slightly higher than that found by Marble and Baxter and Alter with a different sample. This difference is undoubtedly due to varying amounts of common lead which the mineral is known to contain. With a different specimen of Wilberforce uraninite, Baxter and Bliss found 206·195, although the Th/U ratio of this specimen was lower. It is far from certain, however, that Wilberforce uraninite is free from common lead. The lead in the black insoluble portion of Katanga

pitchblende appears to have a slightly higher atomic weight than that in the hydrochloric acid-soluble portion of the same specimen as determined by Hönigschmid, Sachtleben, and Baudrexler, 206·03.

The Atomic Weight of Lead.

	Wt. of $PbCl_2$.	Wt. of Ag.	$PbCl_2$: 2Ag.	At. wt. Pb.	Wt. of AgCl.	$PbCl_2$: 2AgCl.	At. wt. Pb.
Pitchblende, Great Bear Lake, N.W.T., Canada.	4·10802	3·19996	1·28377	206·073			
	3·01366	2·34736	1·28386	206·090			
	3·94641	3·07404	1·28379	206·076	4·08412	0·96628	206·094
	3·00540	2·34110	1·28376	206·069	3·11048	0·96622	206·075
	3·99564	3·11230	1·28382	206·084	4·13520	0·96625	206·085
	5·21141	4·05947	1·28377	206·071	5·39355	0·96623	206·079
		Average	1·28379	206·077		0·96625	206·083
Uraninite, Wilberforce, Ontario, Canada.	3·05552	2·37910	1·28432	206·190	3·16127	0·96655	206·170
	3·02424	2·35477	1·28430	206·187			
	5·01384	3·90390	1·28432	206·190			
	2·57832	2·00763	1·28426	206·178			
		Average	1·28430	206·186			
Pitchblende, Katanga, Africa.	2·90173	2·26061	1·28360	206·037			
	2·77498	2·16174	1·28368	206·053			
Black insoluble.		Average	1·28364	206·045			
Galena, Tetûche.	3·83794	2·97731	1·28907	207·214	3·95559	0·97026	207·234
	4·33839	3·36557	1·28905	207·211	4·47171	0·97019	207·213
	3·41397	2·64831	1·28912	207·224	3·51904	0·97014	207·201
		Average	1·28908	207·216		0·97020	207·216

In the light of recent evidence (see preceding reports) the atomic weight of lead appears to be nearer 207·21 than 207·22 and this change has been made in the table.

URANIUM.—Hönigschmid and Wittner (*Z. anorg. Chem.*, 1936, **226**, 289) have investigated the ratios $UCl_4 : 4Ag : 4AgCl$ and $UBr_4 : 4Ag : 4AgBr$. Samples of uranium material from different mineral sources were purified by essentially similar methods, including removal of heavy metals with hydrogen sulphide, precipitation of uranyl carbonate and solution in excess ammonium carbonate, crystallisation of uranyl nitrate, precipitation of uranyl oxalate and ignition, first to U_3O_8, and then to UO_2 in hydrogen.

The halides were obtained by heating the oxide mixed with sugar charcoal in an atmosphere of nitrogen and chlorine or bromine, and the first sublimate obtained was resublimed into a weighed quartz tube, all in a quartz bottling system. In many of the experiments the sublimed halide was fused in an atmosphere of the corresponding halogen before being weighed. Analysis followed by dissolving the salt, oxidising with hydrogen peroxide in acid solution, and comparison with silver. Afterwards in some cases the silver halides were collected. Weights are corrected to vacuum.

Within the experimental error there seem to be no differences in the isotopic composition of the samples of uranium, although the original minerals differ considerably in geologic age.

The authors believe the comparisons of the halides with silver to be more accurate than those with silver halides, and point out that, since material fused after sublimation seems to yield slightly higher and less consistent results than when final fusion is omitted, dissociation and loss of halogen may occur during fusion. Therefore they prefer the final value 238·07, which results from analyses of unfused chloride, to the average of all the determinations.

This result is materially lower than the value in use for some time, which depends on the work of Hönigschmid and of Hönigschmid and Schilz. The authors believe the difference to be due to the fact that in the earlier work the halides were finally sublimed and fused in nitrogen before weighing. Since there seems to be no doubt that this is the case, and since the value 238·07 best represents the evidence of the foregoing work, this new value has been adopted for the table.

The Atomic Weight of Uranium.

Source.	Wt. of UCl_4.	Wt. of Ag.	UCl_4 : 4Ag.	At. wt. U.	Wt. of AgCl.	UCl_4 : 4AgCl.	At. wt. U.
		Sublimed in chlorine and fused in chlorine.					
Morogoro, Uraninite.	3·08216	3·50091	0·88039	238·077	4·65181	0·66257	238·057
	2·17001	2·46488	0·88037	238·070			
	3·43045	3·89642	0·88041	238·087			
		Average	0·88039	238·078			
		Sublimed in chlorine, not fused.					
Morogoro, Uraninite.	3·43612	3·90301	0·88038	238·072			
	4·37836	4·97304	0·88042	238·091			
	2·90330	3·29784	0·88037	238·067			
	5·49584	6·24257	0·88038	238·074			
	4·90768	5·57455	0·88037	238·070			
	4·99286	5·67158	0·88033	238·052			
	3·75336	4·26323	0·88040	238·084			
	4·77701	5·42582	0·88042	238·092			
	4·47977	5·08841	0·88039	238·077			
			Average	238·075			
Katanga, Curite.	4·63617	5·26634	0·88034	238·056	6·99683	0·66261	238·078
	4·36107	4·95357	0·88039	238·078	6·58181	0·66260	238·069
	4·47121	5·07874	0·88038	238·073	6·74810	0·66259	238·065
		Average	0·88037	238·069		0·66260	238·071
Norwegian Euxenite and Samarskite.	3·18342	3·61604	0·88036	238·065	4·80457	0·66258	238·062
	4·46996	5·07739	0·88037	238·068	6·74596	0·66261	238·080
	4·70546	5·34497	0·88035	238·062	7·10206	0·66255	238·043
		Average	0·88036	238·065		0·66258	238·062
		Sublimed in bromine and fused in bromine.					
Source.	Wt. of UBr_4.	Wt. of Ag.	UBr_4 : 4Ag.	At. wt. U.	Wt. of AgBr.	UBr_4 : 4AgBr.	At. wt. U
Morogoro, Uraninite.	2·42503	1·87618	1·29254	238·091	3·26598	0·74251	238·099
	6·09031	4·71214	1·29247	238·064			
	5·02670	3·88920	1·29248	238·066	6·77004	0·74249	238·084
	4·72075	3·65242	1·29250	238·075			
	4·69691	3·63391	1·29252	238·085	6·32562	0·74252	238·106
	4·32567	3·34676	1·29250	238·073	5·82595	0·74248	238·078
		Average	1·29250	238·075		0·74250	238·092
Joachimsthal, Pitchblende.	4·78298	3·70053	1·29251	238·081	6·44193	0·74248	238·072
	3·49630	2·70491	1·29258	238·108	4·70845	0·74256	238·134
	2·93547	2·27122	1·29246	238·060			
	4·37485	3·38489	1·29246	238·060	5·89220	0·74248	238·076
	3·02257	2·33852	1·29252	238·082	4·07087	0·74249	238·081
	3·45769	2·67520	1·29250	238·075	4·65671	0·74252	238·104
	3·42225	2·64779	1·29249	238·073	4·60899	0·74252	238·102
		Average	1·29250	238·077		0·74251	238·095
Katanga, Curite.	4·00032	3·09498	1·29252	238·084	5·38767	0·74250	238·087
	4·86883	3·76705	1·29248	238·066	6·55730	0·74251	238·094
	4·35228	3·36732	1·29251	238·078	5·86169	0·74250	238·087
	4·42009	3·41976	1·29252	238·082	5·95328	0·74246	238·062
		Average	1·29251	238·078		0·74249	238·083
Norwegian Euxenite and Samarskite.	2·72360	2·10715	1·29255	238·098	3·66815	0·74250	238·090
	2·60119	2·01259	1·29246	238·058	3·50361	0·74243	238·039
	4·20791	3·25555	1·29254	238·090	5·66706	0·74252	238·106
		Average	1·29252	238·082		0·74248	238·078

MOLYBDENUM AND TUNGSTEN.—Hönigschmid and Wittmann (*Z. anorg. Chem.*, **1936**, **229**, 65) and Hönigschmid and Menn (*Z. anorg. Chem.*, 1936, **229**, 49) have redetermined the atomic weights of molybdenum and tungsten by analysis of the pentachloride and hexachloride, respectively.* Their results, Mo = 95·95 and W = 183·92, agree closely with Aston's recent determinations, and are only slightly lower than the International values.

* Published after Sept. 30th, 1936.

New measurements of doublets by Aston (*Nature*, 1936, 137, 357, 613) with a perfected mass spectrograph include the following values for certain light isotopes :

^{16}O = 16·0000	O = 16·0000 (Factor = 1·00025)
H = 1·00812	H = 1·0079
D = 2·01471	D = 2·0142
He = 4·00391	He = 4·0029
^{12}C = 12·0035	^{12}C = 12·0005
^{14}N = 14·0073	^{14}N = 14·0038

The value for ^{12}C is slightly lower than that reported by Aston in 1935, and with an abundance ratio of 1/100 for ^{13}C leads to an atomic weight of 12·010.

ATOMIC WEIGHTS, 1937.

	Symbol.	At. No.	At. wt.
Aluminium	Al	13	26·97
Antimony	Sb	51	121·76
Argon	A	18	39·944
Arsenic	As	33	74·91
Barium	Ba	56	137·36
Beryllium	Be	4	9·02
Bismuth	Bi	83	209·00
Boron	B	5	10·82
Bromine	Br	35	79·916
Cadmium	Cd	48	112·41
Cæsium	Cs	55	132·91
Calcium	Ca	20	40·08
Carbon	C	6	12·01
Cerium	Ce	58	140·13
Chlorine	Cl	17	35·457
Chromium	Cr	24	52·01
Cobalt	Co	27	58·94
Copper	Cu	29	63·57
Dysprosium	Dy	66	162·46
Erbium	Er	68	167·64
Europium	Eu	63	152·0
Fluorine	F	9	19·00
Gadolinium	Gd	64	156·9
Gallium	Ga	31	69·72
Germanium	Ge	32	72·60
Gold	Au	79	197·2
Hafnium	Hf	72	178·6
Helium	He	2	4·002
Holmium	Ho	67	163·5
Hydrogen	H	1	1·0078
Indium	In	49	114·76
Iodine	I	53	126·92
Iridium	Ir	77	193·1
Iron	Fe	26	55·84
Krypton	Kr	36	83·7
Lanthanum	La	57	138·92
Lead	Pb	82	207·21
Lithium	Li	3	6·940
Lutecium	Lu	71	175·0
Magnesium	Mg	12	24·32
Manganese	Mn	25	54·93
Mercury	Hg	80	200·61
Molybdenum	Mo	42	96·0
Neodymium	Nd	60	144·27
Neon	Ne	10	20·183
Nickel	Ni	28	58·69
Niobium (Columbium)	Nb (Cb)	41	92·91
Nitrogen	N	7	14·008
Osmium	Os	76	191·5
Oxygen	O	8	16·0000
Palladium	Pd	46	106·7
Phosphorus	P	15	31·02
Platinum	Pt	78	195·23
Potassium	K	19	39·096
Praseodymium	Pr	59	140·92
Protoactinium	Pa	91	231
Radium	Ra	88	226·05
Radon	Rn	86	222
Rhenium	Re	75	186·31
Rhodium	Rh	45	102·91
Rubidium	Rb	37	85·48
Ruthenium	Ru	44	101·7
Samarium	Sm	62	150·43
Scandium	Sc	21	45·10
Selenium	Se	34	78·96
Silicon	Si	14	28·06
Silver	Ag	47	107·880
Sodium	Na	11	22·997
Strontium	Sr	38	87·63
Sulphur	S	16	32·06
Tantalum	Ta	73	180·88
Tellurium	Te	52	127·61
Terbium	Tb	65	159·2
Thallium	Tl	81	204·39
Thorium	Th	90	232·12
Thulium	Tm	69	169·4
Tin	Sn	50	118·70
Titanium	Ti	22	47·90
Tungsten	W	74	184·0
Uranium	U	92	238·07
Vanadium	V	23	50·95
Xenon	Xe	54	131·3
Ytterbium	Yb	70	173·04
Yttrium	Y	39	88·92
Zinc	Zn	30	65·38
Zirconium	Zr	40	91·22

First Report of the Committee on Atoms of the International Union of Chemistry

Chairman : F. W. ASTON.

N. BOHR, O. HAHN, W. D. HARKINS, G. URBAIN.

THE Committee issues this first Table of Isotopes in the hope that it will be of service to those working on nuclear disintegration. It is not proposed to quote the numerous authorities on which this Table is based, but it will be revised at frequent intervals and supplemented with a Table of Isotopic Weights later. Authors of papers bearing on the subject are requested to send copies to each of the members of the Committee :

Dr. F. W. ASTON, Trinity College, Cambridge.
Professor N. BOHR, University of Copenhagen.
Professor O. HAHN, Kaiser Wilhelm-Institut für Chemie, Berlin-Dahlem.
Professor W. D. HARKINS, University of Chicago, Ill., U.S.A.
Professor G. URBAIN, 1, rue Victor-Cousin, Paris.

International Table of Stable Isotopes for 1936.

(Numbers in italics are rough or indirect measurements, in parentheses doubtful. a, b, c, d are orders of abundance.)

Symbol.	Atomic Number (Z).	Mass Number (M).	Relative Abundance (%).
H	1	1	99·98
D		2	0·02
T		3	(7 × 10⁻⁸)
He	2	4	100
Li	3	6	7·9
		7	92·1
Be	4	(8)	(0·05)
		9	99·95
B	5	10	20
		11	*80*
C	6	12	99·3
		13	0·7
N	7	*14*	*99·62*
		15	0·38
O	8	16	99·76
		17	0·04
		18	0·20
F	9	19	100
Ne	10	20	90·00
		21	0·27
		22	9·73
Na	11	23	100
Mg	12	24	77·4
		25	11·5
		26	11·1
Al	13	27	100
Si	14	28	89·6
		29	6·2
		30	4·2
P	15	31	100
S	16	32	*96*
		33	*1*
		34	*3*
Cl	17	35	76
		37	24

Symbol.	Atomic Number (Z).	Mass Number (M).	Relative Abundance (%).
A	18	36	0·33
		38	0·05
		40	99·62
K	19	39	93·4
		40	0·01
		41	6·6
Ca	20	40	96·76
		42	0·77
		43	0·17
		44	2·30
Sc	21	45	100
Ti	22	46	8·5
		47	7·8
		48	71·3
		49	5·5
		50	6·9
V	23	51	100
Cr	24	50	4·9
		52	81·6
		53	10·4
		54	3·1
Mn	25	55	100
Fe	26	54	6·5
		56	90·2
		57	2·8
		58	0·5
Co	27	59	100
Ni	28	58	68·1
		60	27·2
		(61)	(1·7)
		62	3·8
		64	0·9
Cu	29	63	*68*
		65	*32*
Zn	30	64	50·4
		66	27·2
		67	4·2
		68	17·8
		70	0·4

Symbol.	Atomic Number (Z).	Mass Number (M).	Relative Abundance (%).
Ga	31	69	61·5
		71	38·5
Ge	32	70	21·2
		72	27·3
		73	7·9
		74	37·1
		76	6·5
As	33	75	100
Se	34	74	0·9
		76	9·5
		77	8·3
		78	24·0
		80	48·0
		82	9·3
Br	35	79	50
		81	50
Kr	36	78	0·42
		80	2·45
		82	11·79
		83	11·79
		84	56·85
		86	16·70
Rb	37	85	72
		87	28
Sr	38	86	10·0
		87	6·6
		88	83·4
Y	39	89	100
Zr	40	90	48
		91	11·5
		92	22
		94	17
		96	1·5
Nb [Cb]	41	93	100
Mo	42	92	14·2
		94	10·0
		95	15·5
		96	17·8
		97	9·6
		98	23·0
		100	9·8
Ru	44	96	*5*
		(98)	
		99	*12*
		100	*14*
		101	*22*
		102	*30*
		104	*17*
Rh	45	103	100
Pd	46	102	c
		104	a
		105	a
		106	a
		108	a
		110	b
Ag	47	107	52·5
		109	47·5
Cd	48	106	1·5
		108	1·0
		110	15·6
		111	15·2
		112	22·0
		113	14·7
		114	24·0
		116	6·0
In	49	113	4·5
		115	95·5
Sn	50	112	1·1
		114	0·8
		115	0·4
		116	15·5
		117	9·1
		118	22·5
		119	9·8
		120	28·5
		122	5·5
		124	6·8
Sb	51	121	56
		123	44
Te	52	122	2·9
		123	1·6
		124	4·5
		125	6·0
		126	19·0
		128	32·8
		130	33·1
I	53	127	100
Xe	54	124	0·08
		126	0·08
		128	2·30
		129	27·13
		130	4·18
		131	20·67
		132	26·45
		134	10·31
		136	8·79
Cs	55	133	100
Ba	56	135	5·9
		136	8·9
		137	11·1
		138	74·1
La	57	139	100
Ce	58	140	89
		142	11
Pr	59	141	100
Nd	60	142	36
		143	11
		144	30
		145	5
		146	18
Sm	62	144	3
		147	17
		148	14
		149	15
		150	5
		152	26
		154	20
Eu	63	151	50·6
		153	49 4
Gd	64	155	21
		156	23
		157	17
		158	23
		160	16
Tb	65	159	100
Dy	66	161	22
		162	25
		163	25
		164	28

Symbol.	Atomic Number (Z).	Mass Number (M).	Relative Abundance (%).
Ho	67	165	100
Er	68	166	36
		167	24
		168	30
		170	10
Tm	69	169	100
Yb	70	171	9
		172	24
		173	17
		174	38
		176	12
Lu [Cp]	71	175	100
Hf	72	176	5
		177	19
		178	28
		179	18
		180	30
Ta	73	181	100
W	74	182	22·6
		183	17·3
		184	30·2
		186	29·9
Re	75	185	38·2
		187	61·8
Os	76	186	1·0
		187	0·6
		188	13·4
		189	17·4
		190	25·1
		192	42·5

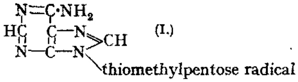
Symbol.	Atomic Number (Z).	Mass Number (M).	Relative Abundance (%).
Ir	77	191	33
		193	67
Pt	78	192	d
		194	b
		195	a
		196	a
		198	c
Au	79	197	100
Hg	80	196	0·10
		(197)	(0·01)
		198	9·89
		199	16·45
		200	23·77
		201	13·67
		202	29·27
		203	0·006
		204	6·85
Tl	81	203	29·4
		205	70·6
Pb	82	(203)	
		204	1·50
		(205)	
		206	23·3
		207	20·1
		208	50·1
		(209)	
		(210)	
Bi	83	209	100
Th	90	232	(100)
U	92	235	< 1
		238	> 99

400. *The Constitution of the Purine Nucleosides. Part V. Adenine Thiomethylpentoside.*

By Roderick Falconer and J. Masson Gulland.

In Part IV (J., 1936, 765) it was shown that in adenosine and the related nucleotides the pentose molecule is attached to position 9 of the adenine molecule. This conclusion was based on the resemblance of the ultra-violet absorption spectra of adenosine, the adenine nucleotides and inosine on the one hand, and those of 9-methyladenine and 9-methylhypoxanthine on the other, and on their mutual dissimilarity to the spectra of 7-methyladenine and 7-methylhypoxanthine.

The method has now been extended to the examination of adenine thiomethylpentoside, which was isolated from yeast, from oryzanin and from impure cozymase (Mandel and Dunham, *J. Biol. Chem.*, 1912, **11**, 85; Suzuki, *J. Chem. Soc. Tokyo*, 1914, **34**, 1134; Levene, *J. Biol. Chem.*, 1924, **59**, 465; Suzuki, Odake, and Mori, *Biochem. Z.*, 1924, **154**, 278; v. Euler and Myrbäck, *Z. physiol. Chem.*, 1928, **177**, 237), and yielded adenine and thiomethylpentose when hydrolysed (Suzuki *et al.*, *loc. cit.*; Levene and Sobotka, *J. Biol. Chem.*, 1925, **65**, 551).



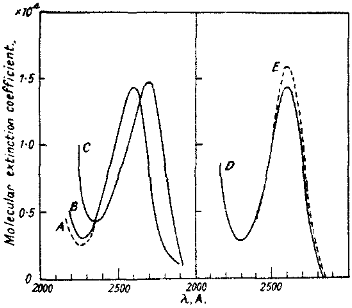
(I.)

(The constitution of thiomethylpentose has not yet been determined.)

The ultra-violet absorption spectra of adenine thiomethylpentoside in aqueous, acid and alkaline solutions (Fig. 2; peak at 2600A.; compare Heyroth and Loofbourow, *J. Amer. Chem. Soc.*, 1934, **56**, 1728) closely resemble those of adenosine and 9-methyladenine in similar conditions and are unlike those of 7-methyladenine (Fig. 1, taken from Part IV). It follows, therefore, that in adenine thiomethylpentoside (I) the thio-sugar is attached to position 9.

We are greatly indebted to Professor U. Suzuki, President of the Continental Institute for Scientific Research, Hsingking, Manchukuo, for a gift of adenine thiomethylpentoside. Measurements were made with a Bellingham and Stanley quartz spectrograph No. 2 and photometer, the light source being a condensed spark between tungsten-steel electrodes. The

FIG. 1. FIG. 2.



A. *Adenosine in water*, N/20-HCl, *and* N/20-NaOH.
B. 9-*Methyladenine in water*, N/20-HCl, *and* N/20-NaOH.
C. 7-*Methyladenine in water and* N/20-HCl.
D. *Adenine thiomethylpentoside in water*, N/20-HCl, *and* N/20-NaOH.
E. *Adenine thiomethylpentoside in* N/20-NaOH *at* 1·5 *hours after preparation of the solution.*

solutions, prepared from dried material and made to a strength of M/100,000, were examined immediately in a layer thickness of 4 cm. against controls. The peaks of the spectra of adenine thiomethylpentoside all lay at 2600A.

It was observed that the extinction coefficient of adenine thiomethylpentoside in alkaline solution had increased when a short time had elapsed after its preparation, the wave-length of the peak, however, remaining unchanged (Fig. 2).

UNIVERSITY COLLEGE, NOTTINGHAM. [*Received, November 5th*, 1937.]

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401. *The Acylation of Diazomethane. Part II. The Reaction of Diazomethane with O-Acetylmandelyl Chloride and Some Transformations of the Product.*

By WILLIAM BRADLEY and JOHN KENNETH EATON.

The properties of the diazomethyl ketone from *O*-acetylmandelyl chloride and diazomethane are studied in relation to the use of compounds of this type as intermediates in the preparation of α-phenylglycerol derivatives from substituted mandelic acids. The diazo-ketone and hydrogen chloride give the related *chloro-ketone*, and this is changed either by keeping or by heating with methyl-alcoholic sodium acetate into acetylbenzoyl. Benzylglyoxal is formed when the diazo-ketone reacts with dilute sulphuric acid.

THE interest which is attached to arylglycerols as possible intermediates in phytochemical changes (cf. Robinson, *Nature*, 1936, **137**, 172) suggested an attempt to prepare compounds of this type from diazomethyl ketones, since these are readily accessible from the related

carboxylic acids (Bradley and Robinson, J., 1928, 1310, 1545; Bradley and Schwarzenbach, *ibid.*, p. 2904, now regarded as Part I). *O*-Acetylmandelyl chloride (I), added to ethereal diazomethane (at least two molecular proportions), gave an oily diazomethyl ketone (II), which with dry hydrogen chloride afforded the *chloro-ketone* (III). The diazomethyl ketone did not react easily with acetic acid, but dilute sulphuric acid decomposed it, forming a product which reduced Fehling's solution in the cold. The only crystalline compound isolated from the reaction product was benzylglyoxal, m. p. 119—120° (V) (Dakin and Dudley, *J. Biol. Chem.*, 1914, **18**, 42, state m. p. 120—122°, softening at 115°), further characterised by the preparation of a *dioxime*, m. p. 163°. Apparently the glyoxal derivative is formed by hydrolysis of *O*-acetylphenyldihydroxyacetone (IV) and rearrangement of the product. The result recalls the dehydration of dihydroxyacetone to methylglyoxal in acid solution (Pinkus, *Ber.*, 1898, **31**, 36). No compound which reduced Fehling's solution could be obtained when the chloro-ketone was heated with water alone or in presence of magnesium carbonate. Heating with methyl-alcoholic sodium acetate gave, not the expected acetoxy-ketone, but acetylbenzoyl (VI), a dioxime of which was compared directly with an authentic specimen prepared by the method of Borsche (*Ber.*, 1907, **40**, 737). Except when carefully purified, samples of the chloro-ketone decomposed on keeping with liberation of hydrogen chloride and formation of acetylbenzoyl.

$$\underset{\text{(I.)}}{\mathrm{Ph{\cdot}CH(OAc){\cdot}COCl}} \xrightarrow{\mathrm{CH_2N_2}} \underset{\text{(II.)}}{\mathrm{Ph{\cdot}CH(OAc){\cdot}CO{\cdot}CHN_2}} \xrightarrow[\mathrm{H_2SO_4}]{\text{dil.}} \underset{\text{(IV.)}}{\mathrm{Ph{\cdot}CH(OAc){\cdot}CO{\cdot}CH_2{\cdot}OH}}$$

$$\text{(II.)} \xrightarrow{\mathrm{HCl}} \text{(III.)} \qquad \text{(IV.)} \longrightarrow \text{(V.)}$$

$$\underset{\text{(VI.)}}{\mathrm{Ph{\cdot}CO{\cdot}CO{\cdot}CH_3}} \xleftarrow{\mathrm{NaOAc}} \underset{\text{(III.)}}{\mathrm{Ph{\cdot}CH(OAc){\cdot}CO{\cdot}CH_2Cl}} \qquad \underset{\text{(V.)}}{\mathrm{Ph{\cdot}CH_2{\cdot}CO{\cdot}CHO}}$$

Experimental.

Chloromethyl α-Acetoxybenzyl Ketone (III).—A solution of diazomethane (8·8 g.) in ether (1100 c.c.) was added in a thin stream to a well-stirred solution of freshly prepared acetylmandelyl chloride (35·5 g.) in dry ether (100 c.c.). Nitrogen was liberated. After keeping overnight, dry hydrogen chloride was admitted until no further evolution of nitrogen occurred and the solution had become almost colourless. It was washed with water, sodium bicarbonate solution, and finally with dilute acetic acid. After drying and removal of the solvent under reduced pressure the residue solidified to a white crystalline mass (36·5 g.). Recrystallisation from light petroleum gave colourless prisms, m. p. 57° (Found: C, 58·2; H, 4·9; Cl, 15·6. $C_{11}H_{11}O_3Cl$ requires C, 58·3; H, 4·9; Cl, 15·7%). The *chloro-ketone* reduced Fehling's solution in the cold.

Acetylbenzoyl (VI).—A solution of the chloro-ketone (9·2 g.) in methyl alcohol (50 c.c.) was added to anhydrous sodium acetate (12 g.) and glacial acetic acid (2·4 c.c.) in methyl alcohol (100 c.c.). After 3 hours' boiling, the precipitated sodium chloride was removed; no further precipitation occurred when the solution was boiled 2 hours longer. Most of the alcohol was distilled off, and the residue dissolved in ether and water. The ethereal solution, washed with aqueous sodium bicarbonate and dried, gave on evaporation of the solvent a yellow oil (10 g.), from which benzoic acid separated on keeping. A portion of the oil (0·5 g.) was warmed with sodium acetate (1 g.) and hydroxylamine hydrochloride (1 g.) in aqueous alcoholic solution at 45° during 6 hours and then at 80° for 12 hours longer. Water then precipitated a white crystalline derivative (0·3 g.), m. p. 236—237° after recrystallisation from alcohol (Found: C, 60·3; H, 5·6; N, 15·9. Calc. for $C_9H_{10}O_2N_2$: C, 60·7; H, 5·6; N, 15·7%). A red nickel complex was precipitated when an alcoholic solution of the derivative was added to aqueous nickel sulphate containing a little ammonia. No depression of m. p. was observed when the compound was mixed with a sample of acetylbenzoyldioxime, m. p. 235—236°, prepared by Borsche's method (*loc. cit.*).

When the chloro-ketone (1 g.) was heated with water (10 c.c.) and magnesium carbonate (0·5 g.) at 100° during 24 hours, a reddish oil was obtained which did not reduce Fehling's solution. Estimation of the extent to which hydrolysis had proceeded gave the following results: Found in solution: HCl, 0·12 g.; $CH_3{\cdot}CO_2H$, 0·24 g. Calc. for complete hydrolysis: HCl, 0·16 g.; $CH_3{\cdot}CO_2H$, 0·265 g.

Spontaneous Decomposition of the Chloro-ketone.—Hydrogen chloride was liberated and a

brown oil with reducing properties was obtained when a sample of the chloro-ketone (m. p. 55—56°) was kept during 12 months in a closed tube. Treatment of a portion of the oil (1·5 g.) with sodium acetate and hydroxylamine hydrochloride gave almost pure acetylbenzoyldioxime (1·75 g., m. p. 232°). Recrystallisation of the dioxime from dilute alcohol gave flat slender prisms, m. p. 236—237°, not depressed after mixing with an authentic specimen prepared by the method of Borsche (*loc. cit.*).

Benzylglyoxal (V).—*O*-Acetylmandelyl chloride (17·5 g.) ("Organic Syntheses," **4**, 1), dissolved in dry ether (100 c.c.), was added through a capillary tube during 2 hours to a stirred, ice-cold solution of diazomethane (9·2 g.) in ether (850 c.c.). Nitrogen was evolved freely. After keeping overnight a portion of the solution was evaporated in a current of air; a yellow oil remained which could not be obtained crystalline. The remainder of the solution was concentrated by the same means to 500 c.c., and then shaken with a mixture of concentrated sulphuric acid (25 g.) and water (60 c.c.). Evolution of nitrogen occurred, greatly facilitated by the addition of porous tile. After a few hours, reaction had ceased and the ethereal solution had become only pale yellow, whilst the colour of the aqueous layer had become deep yellow.

The ethereal layer was separated, washed with sodium bicarbonate solution and water, and dried (sodium sulphate). When the solvent was allowed to evaporate, a viscous yellow oil remained. A portion (2 g.) was dissolved in alcohol, and alcoholic 2 : 4-dinitrophenylhydrazine added until a precipitate no longer formed. The hydrazone was boiled out with glacial acetic acid (25 c.c.), and the undissolved material crystallised from the same solvent. Slender orange-red prisms were obtained (Found : C, 54·6; H, 3·6. Calc. for $C_{15}H_{10}O_4N_4$: C, 54·5; H, 3·6%), m. p. 234°, not depressed by benzaldehyde-2 : 4-dinitrophenylhydrazone (m. p. 235°).

The aqueous acid layer was diluted with an equal volume of water. After 4—5 weeks long colourless needles and a little reddish-brown oil had separated from solution; the crystals were collected, m. p. 113—115°. After an equal time a further crop of crystals, m. p. 112—115°, was obtained. The total yield was 1·5 g. Repeated crystallisation from benzene gave pure benzylglyoxal, m. p. 119—120° (Found : C, 72·7; H, 5·4. Calc. for $C_9H_8O_2$: C, 72·9; H, 5·4%).

Benzylglyoxime.—0·1 G. of the compound, m. p. 119—120°, dissolved in alcohol (2 c.c.), was warmed at 45° during 12 hours and then at 80° during 6 hours with a concentrated aqueous solution of sodium acetate (0·1 g.) and hydroxylamine hydrochloride (0·1 g.) Water was then added, and the crystalline *product* recrystallised from aqueous alcohol; glistening white leaflets (0·07 g.) were obtained, m. p. 163° (Found : C, 60·7; H, 5·6; N, 15·5. $C_9H_{10}O_2N_2$ requires C, 60·7; H, 5·6; N, 15·7%).

Attempts to prepare α-phenylglycerol by reducing either the ether-solubie oil or the water-soluble product were unsuccessful.

One of the authors (J. K. E.) thanks the Manchester Education Committee for a Research Scholarship which enabled him to take part in the work.

College of Technology, Manchester. [*Received, November 5th,* 1937.]

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402. *The Magnitude of the Solvent Effect in Dipole-moment Measurements. Part I. The Polarisation of Carbon Tetrachloride Solutions.*

By F. R. Goss.

The dielectric polarisation of polar substances in solution is known to differ from the same polarisation measured in the vapour state by amounts which are described in general as "solvent effects." It is already known that these are connected with the electrical anisotropy of the solvent, the concentration, anisotropy, and degree of association of the solute, and any chemical reaction which may occur between solvent and solute.

It is now shown that for certain solutions of polar substances in the isotropic solvent, carbon tetrachloride, the variation in the partial molar polarisations (P_2), obtained by the method of intercepts from the polarisations (P_{12}) of the mixtures, can be expressed as a function of the dielectric constant ε in the form

$$P_2 = P_{E+A} + Z(\varepsilon - 1)^4/(\varepsilon + 2)^4 + Y/\varepsilon$$

Here Y and Z are molar quantities whose ratios (Y/P_0 and Z/P_{E+A}) to the orientation and to the distortion polarisations respectively are, in the same way as $(P_\infty - P_{E+A})/P_0$, a measure of the modification of the magnitude of the polarisation by the anisotropy. These quantities are found to be related by the formula

$$(Y/P_0 - 1)/[\sqrt[4]{(Z + P_{E+A})/P_{E+A}} - 1] = 3{\cdot}25$$

by means of which the solvent effects due to anisotropy and change of concentration may readily be defined and calculated.

Values for the dipole moment obtained by means of these formulæ from suitable experimental data are in satisfactory agreement with those given by the vapour measurements.

FOLLOWING the successful interpretation (J., 1933, 1341) of the temperature variation of the polarisation of certain non-polar liquids in terms of dielectric anisotropy, an attempt was made (J., 1934, 696, 1467) to find a theoretical basis for Sugden's relation (*Nature*, 1934, **133**, 415)

$$P_2 = P_{E+A+O} + \alpha - P_O(\varepsilon - 1)/(\varepsilon + 2) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

for the dielectric polarisation P_2 of one component of a liquid mixture in terms of the total and the orientation polarisation, P_{E+A+O} and P_O, of the same substance in the state of vapour, and the dielectric constant of the mixture, the term α being obtained experimentally. This simple formula was found to require modification (cf. J., **1935**, **502**) when applied to mixtures of carbon tetrachloride and nitrobenzene [an example chosen both for the isotropic nature of the non-polar solvent (cf. J., 1935, 727) and for the wide range covered by the values of ε in this case]. It was found that a close approximation to the experimental data is given by the expression

$$P_2 = P_{E+A+O} - B\{(\varepsilon - 1)/(\varepsilon + 2) + (\varepsilon - 1)^2/(\varepsilon + 2)^2\} \quad . \quad . \quad . \quad (2)$$

Unfortunately (1) and (2) are not generally applicable to mixtures of other liquids which have been examined, and it is evident that agreement between such formulæ and the data must be largely fortuitous because the values of P_2 are calculated on the quite arbitrary assumption, due in the first place to Debye (Marx, "Handbuch der Radiologie," 1925, **6**, 630), that the polarisation P_1 of the other component is independent of the concentration c_2. This assumption admittedly leads to the correct value for the polarisation P_∞ of the solute at infinite dilution ($c_2 = 0$), although considerable uncertainty must necessarily be introduced into the extrapolation because of the arithmetical difficulty involved in employing the expression (3) at small values of c_2.

$$P_2 = (P_{12} - P_1)/c_2 + P_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

On the other hand, the values of P_2 given by formula (3) for finite values of c_2 will be wrong to the extent that Debye's assumption of the invariability of P_1 is in error.

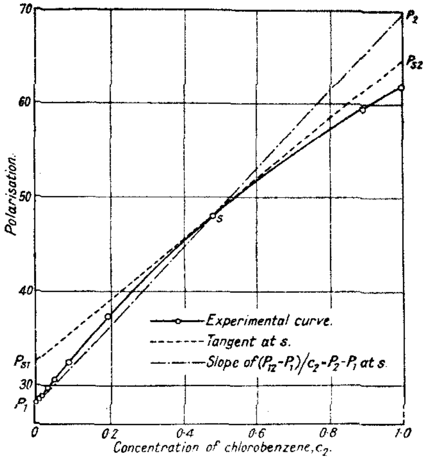
Orr and Butler (*Nature*, 1932, **130**, 930) believe that the intercept method * gives the partial polarisations of the components of a mixture at all concentrations, and in this communication an attempt is made to interpret the intercepts (P_{S1} and P_{S2}) given by tangents to P_{12} curves at the axes where $c_2 = 0$ and 1 (see Fig. 1) in the expectation that they represent the partial polarisations more exactly than P_1 and P_2 obtained in the usually accepted manner.

As an example of the method, in Fig. 1 values of P_{12} for chlorobenzene (Table III) are plotted against c_2, and it will be seen that the tangent at the point where $c_2 = 0{\cdot}47942$, one of the experimental points, gives the intercepts of $P_{S1} = 33$ and $P_{S2} = 65$ as the partial polarisations of carbon tetrachloride and chlorobenzene respectively at this concentration, whereas by (3) the values are $P_1 = 28$ and $P_2 = 70$.

Now, it is undoubtedly true that, since the intercepts may be read with almost equal accuracy at all concentrations, P_∞, which is the intercept given by the tangent at the point where $c_2 = 0$, is obtainable more accurately and more readily than by extrapolation

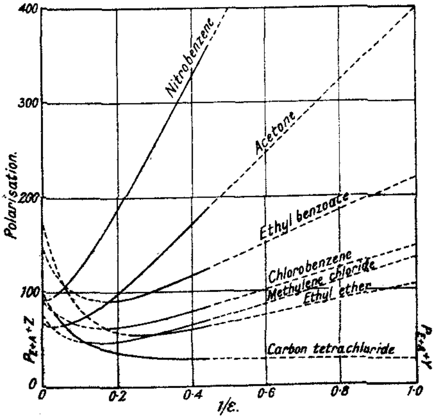
* The author is greatly indebted to Dr. W. Wild, who directed his attention to the possible application of this method to the interpretation of polarisation data.

FIG. 1.



Polarisation of chlorobenzene and carbon tetrachloride at 20°.

FIG. 2.



Partial molar polarisations at 20° $P_B = P_{E+A} + Z(\epsilon - 1)^4/(\epsilon + 2)^4 + Y/\epsilon$ ***extrapolated to*** $\epsilon = 1$ ***and*** $\epsilon = \infty$.

of P_2. Further, it will be seen from the data given in Table I that the intercepts obtained from mixtures of carbon tetrachloride with several polar substances, each component being considered independently, can be expressed as a function of the dielectric constant:

$$P_S = P_{E+A} + Z(\epsilon - 1)^4/(\epsilon + 2)^4 + Y/\epsilon \quad . \quad . \quad . \quad . \quad . \quad (4)$$

The values of P_S given by (4), which are also given in Fig. 2, are seen to coincide with the actual intercepts except for minor deviations in the case of the higher concentrations of ethyl ether, nitrobenzene, and carbon tetrachloride; in the other four cases agreement is exact.

TABLE I.

$t = 20°$.

c_2.	P_{S_2}.	P_{S_1}.	P_{S_2} [calc. by (4)].
Nitrobenzene (Pal, *Phil. Mag.*, 1930, **10**, 265); $[R_L]_D = 32·7$; $P_{E+A} = 34·3$.			
0·00000	365	28·0	365
0·00985	337	28·1	337
0·02101	311	28·6	310
0·03193	290	29·2	288
0·04686	264	30·4	263
0·07064	232	32·5	231
0·09586	205	35	205
0·1527	167	41	168
0·2098	143	47	144
0·3103	119	54	124
0·4039	109	59	112
0·5001	103	64	105
0·5917	99	68	102
0·7166	96	72	98
0·8046	95	75	97
0·8936	94·7	78	95
1·0000	94·5	80	94·5
Ethyl benzoate (see Table III); $[R_L]_D = 42·6$; $P_{E+A} = 44·7$.			
0·00000	124	28·1	124
0·00645	123	28·1	123
0·01351	122	28·1	122
0·03413	119	28·2	119
0·05252	116	28·4	116
0·06868	114	28·5	114
0·10835	109	29	110
0·18000	103	30	104
0·41006	94	34	94
0·67061	91	38	91
1·00000	89·8	42	89·8
Methylene chloride (Morgan and Lowry, *J. Physical Chem.*, 1930, **34**, 2385); $[R_L]_D = 16·3$; $P_{E+A} = 17·1$.			
0·00000	70	28·2	70
0·25000	57	30	57
1·00000	46·8	53	46·8
Chlorobenzene (see Table III); $[R_L]_D = 31·2$; $P_{E+A} = 32·8$.			
0·00000	85	28·1	85
0·00806	84	28·1	84
0·01531	83	28·1	83
0·03142	82	28·2	82
0·04812	81	28·2	81
0·08478	79	28·2	79
0·18906	74	29	74
0·47942	65	33	66
0·89470	62	39	62
1·00000	61·8	40	61·8
Acetone (Earp and Glasstone, J., 1935, 1720); $[R_L]_D = 16·1$; $P_{E+A} = 16·9$.			
0·00000	188	28·3	188
0·04186	161	29	161
0·09496	136	31	136
0·20665	104	36	104
0·35814	82	46	81
0·57880	70	54	70
0·75685	66	61	66
0·89866	64	66	64
0·97431	64	68	64
1·00000	63·9	68	63·9
Ethyl ether (Earp and Glasstone, J., 1935, 1709); $[R_L]_D = 22·5$; $P_{E+A} = 23·6$.			
0·00000	62	28·3	62
0·03862	61	28·3	61
0·06053	60	28·4	60
0·11003	59	28·5	59
0·15809	58·5	28·6	58·5
0·20399	57·7	28·7	57·7
0·26413	57·2	28·8	56·8
0·32161	56·8	29·0	56·0
0·44406	56·2	29·4	54·9
0·48548	56·1	29·5	54·6
0·58144	55·7	30	54·1
0·70024	55·3	31	54·0
0·81740	55·0	33	54·1
0·90979	54·8	34	54·4
1·00000	54·7	35	54·7

The values of Z and Y for the seven substances investigated are given in Table II, and it will be seen that they are the intercepts (less P_{E+A}) given by expression (4) on the P_S axis where $\epsilon = \infty$ and 1, or, more conveniently for graphical representation, where $1/\epsilon = 0$ and 1. For carbon tetrachloride, $Y = 0$, and it follows that $Z(\epsilon - 1)^4/(\epsilon + 2)^4$ is an additional term in the distortion polarisation of the liquids involved in these solutions, and hence that Y/ϵ is their orientation polarisation. When $\epsilon = \epsilon_1$ (ϵ_1 being the dielectric constant of the non-polar component) and $P_S = P_\infty$, as in the infinitely dilute

solution, or, for carbon tetrachloride, as in the pure liquid (here $P_S = P_1$), the second term of the expression (4) is negligible, so that

$$Y/\varepsilon_1 = P_\infty - P_{E+A} \text{ (approx.)} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

Further examination of the data shows that within the limits of experimental error

$$(Y/P_O - 1)/[\sqrt[4]{(Z + P_{E+A})/P_{E+A}} - 1] = 3{\cdot}25 \quad . \quad . \quad . \quad . \quad (6)$$

Even in the case of carbon tetrachloride, where both Y and P are zero, this ratio can be calculated by making use of the relation between $(P_\infty - P_{E+A})/P_O$ and molecular symmetry elaborated by Higasi (*Sci. Papers Inst. Phys. Chem. Res. Tokyo*, **1936**, **28**, 284), from which it may be assumed that for an isotropic substance such as carbon tetrachloride, although both sides of the expression are zero, yet in the limit $P_\infty - P_{E+A} = P_O$ and hence from (5), $Y/P_O = \varepsilon_1$. Moreover, it follows from (5) that Y/P_O is very nearly ε_1 times the ratio $(P \ \ - P_{E+A})/P_O$, which Higasi found to be connected with the relationship between the direction of the dipole and the direction and magnitude of the molecular axes. Thus $Y/\varepsilon_1 P_O$ and Z/P_{E+A}, which are listed in Table II, express the extent to which the orientation and the distortion polarisation respectively are modified by induction.

TABLE II.

$t = 20°$.

	Z.	Y.	Value of (6).	Z/P_{E+A}.	$Y/\varepsilon_1 P_O$.*	μ (calc. by (7)).	μ (vapour).
Nitrobenzene	56	733	3·49	1·62	0·84	4·30	4·23
Chlorobenzene	64	115	2·93	1·95	0·90	1·65	1·69
Ethyl benzoate	104	176	3·54	2·32	0·94	1·99	1·95
Carbon tetrachloride	72	0	3·25	2·61	1·00	0	0
Acetone	50	383	3·08	2·98	1·05	2·79	2·84
Methylene chloride	59	118	3·04	3·45	1·11	1·50	1·53
Ethyl ether	154	84	3·08	6·51	1·40	1·13	1·14

P_O in (6) (col. 4) is the vapour value taken from the literature.
P_O in col. 6 is calculated by expression (7).
* This ratio is approximately the same as $(P_\infty - P_{E+A})/P_O$.

From the relation (6) it follows that

$$P_O = Y/[3{\cdot}25\sqrt[4]{(Z + P_{E+A})/P_{E+A}} - 2{\cdot}25] \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

whence the moment may be calculated in the usual manner. The values obtained are included in Table II with the comparable moments obtained from measurements on the vapours. Finally, it must be stated that P_{E+A} has been taken as 5% greater than $[R_L]_D$ because this gives very closely the known value of P_{E+A} in the case of carbon tetrachloride, but it is evident that uncertainty regarding the value of P_A, and, indeed, the probability that both P_E and P_A vary with the dielectric constant of the mixture, must undoubtedly be a source of error in the values of μ from both vapour and solution data.

EXPERIMENTAL.

Density, dielectric constant, and temperature were measured as previously described (Goss, J., **1933**, 1343; **1935**, 730).*

Purification of Materials.—Carbon tetrachloride. An 'AnalaR' sample was fractionally distilled, and the middle portion collected. It was dried over calcium chloride and again fractionally distilled. The middle fraction had a b. p. range of less than 0·1°.

Chlorobenzene. This was shaken with dilute sulphuric acid, washed with sodium hydroxide solution and distilled water, dried over calcium chloride, and fractionally distilled. The middle fraction boiled at constant temperature.

Ethyl benzoate. This was washed with sodium carbonate solution, shaken several times with distilled water, and dried over potassium carbonate. A final purification was effected by fractionation under reduced pressure and separation of the middle fraction.

* The method of calibrating the condenser, there attributed to Piekara (*Bull. Acad. Polonaise*, **1933**, *A*, 305), had previously been described by Smith (*Proc. Roy. Soc.*, **1932**, *A*, **138**, 251).

Results.—The experimental data and the polarisations (P_{12}) calculated therefrom are recorded in Table III.

TABLE III.

c_2.	ε.	$d_{4^\circ}^{20^\circ}$.	P_{12}.	c_2.	ε.	$d_{4^\circ}^{20^\circ}$.	P_{12}.
Chlorobenzene.				*Ethyl benzoate.*			
0·00000	2·2324	1·5942	28·10	0·00000	2·2348	1·5940	28·14
0·00806	2·2593	1·5901	28·54	0·00645	2·2685	1·5890	28·76
0·01531	2·2849	1·5865	28·96	0·01351	2·3039	1·5832	29·43
0·03142	2·3371	1·5782	29·80	0·03413	2·4069	1·5669	31·32
0·04812	2·3917	1·5699	30·65	0·05252	2·5020	1·5526	33·01
0·08478	2·5142	1·5515	32·50	0·06868	2·5828	1·5404	34·43
0·18906	2·8640	1·4978	37·36	0·10835	2·7811	1·5107	37·83
0·47942	3·8257	1·3544	48·00	0·18000	3·0935	1·4600	43·12
0·89470	5·2867	1·1557	59·49	0·41006	4·0944	1·3173	58·17
1·00000	5·6483	1·1063	61·81	0·67061	5·0516	1·1800	73·69
				1·00000	6·0171	1·0463	89·78

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THE UNIVERSITY, LEEDS, 2. [*Received, July 3rd,* 1937.]

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403. *Investigations on the Configuration of Carbohydrates by Conductivity Measurements in Boric Acid Solution.*

By H. T. MACPHERSON and E. G. V. PERCIVAL.

Böeseken's conclusions on the configuration of α- and β-*d*-glucose are confirmed, since conductivity and viscosity experiments with glucose, α-methylglucoside, and various methylated glucose derivatives make it clear that the only hydroxyl groups in glucose having any effect on the conductivity of a boric acid solution are those on C_1 and C_2. By using 3 : 4 : 6-trimethyl α-mannopyranose, the configuration is shown to be *trans*- with respect to the hydroxyl groups on C_1 and C_2, in contradistinction to Böeseken's results for β-mannose.

A striking elevation of conductivity is found for α-methylmannofuranoside, which is attributed to the orientation of the hydroxyl groups, four being situated in close proximity to one another; γ-methylglucoside, where three hydroxyl groups are close to one another, gives a lower elevation, and γ-methylgalactoside a depression. The behaviour of α-*l*-sorbose appears to be anomalous.

IN a series of papers during 25 years Böeseken and his co-workers developed a method by means of which the structure of α-*d*-glucose was indicated to be of the *cis*-configuration with reference to the hydroxyl groups on C_1 and C_2. This conclusion was derived from the fact that α-glucose exhibited a higher conductivity than β-glucose in boric acid, and also that during mutarotation the conductivity of the α-glucose–boric acid solution fell, and that of the β-glucose–boric acid rose, to an intermediate equilibrium value (*Ber.*, 1913, **46**, 2612). From these facts Böeseken considered that complex formation occurred between boric acid and the hydroxyl residues on C_1 and C_2 in the case of α-glucose but not β-glucose. Although other methods of determining configuration, such as optical calculations (Freudenberg, Helferich, and Winkler, *Z. physiol. Chem.*, 1932, **209**, 270), *X*-ray studies (Cox *et al.*, J., 1932, 138, *et seq.*), and methods depending on differences of reactivity (Micheel and Micheel, *Ber.*, 1930, **63**, 386; Vavon, *Bull. Soc. chim.*, 1931, **49**, 997, 1011), have been elaborated, it seemed to us that this elegant method, if substantiated, might be of service particularly with regard to the structure of dissolved molecules.

It must be borne in mind, however, that in a molecule such as glucose with five free hydroxyl groups, other possibilities of combination with boric acid exist. Irvine and Steele (J., 1915, **107**, 1221) recognised this and examined methylated glucoses, and on the basis of a considerable elevation in conductivity following an initial depression for tetramethyl glucopyranose and an elevation for tetramethyl methylglucoside in boric acid

solution, concluded that the oxygen atom of the ring combined with water to form an oxonium hydrate, which in turn formed a complex, together with the hydroxyl group on C_1, with boric acid. Böeseken and Couvert (*Rec. trav. chim.*, 1921, **40**, 354) repeated this work on purer specimens and found that, instead of the rapid increase of conductivity in boric acid solution, the initial depression underwent little change. We have now confirmed this result and extended it to α-methylglucopyranoside, 2 : 3 : 6-trimethyl glucopyranose, 2 : 3 : 6-trimethyl methylglucopyranoside, and sucrose. In all these cases diminution of conductivity below the sum of the values for the sugar derivative alone and of the boric acid solution was observed with no appreciable increase on standing. Viscosity determinations indicated that the observed depression ran parallel to the relative viscosity, so the diminution in conductivity was not anomalous. Incidentally, it was shown that Einstein's equation (*Ann. Physik*, 1906, **19**, 289), according to which viscosity is a function of the volume of the dissolved phase for approximately spherical molecules, was obeyed by these substances.

It is clear, therefore, not only that the ring oxygen atom, whether in a pyranose or a furanose sugar, has no effect on the conductivity of a boric acid solution, but also that in the case of glucose, the only hydroxyl groups having a positive effect are those on C_1 and C_2. No increase in conductivity is observed unless both these hydroxyl groups are unsubstituted and in the *cis*-position to one another.

Although the change in conductivity during the mutarotation of glucose is explained, it is to be noted that α-methylglucoside depresses the conductivity of boric acid solution; β-glucose in boric acid solution, however, gives, not the expected depression, but an initial elevation of the same order as the difference between the initial conductivities of the α- and the β-glucose. It may be that this initial conductivity is due to the presence in solution of a small amount of a straight-chain aldehydic form, possibly present as the aldehydrol. Straight-chain polyhydroxy-compounds such as dulcitol and sorbitol have a strongly positive effect on the conductivity of boric acid solution (*ca.* 600 × 10^{-6} mho* in M/2-solution), and it was found that glucose diethylmercaptal also had a strong positive effect (176 in M/10-solution).

The case of mannose is of interest since the earlier conductivity results indicate β-*d*-mannose to be a *trans*-form on the basis of a rise in conductivity during mutarotation, contrary to the accepted views for the configuration of this sugar. This case is complicated by the difficulty of securing β-mannose sufficiently pure for conductivity determinations, although our result for β-mannose is opposed to that of Böeseken and Couvert (*Rec. trav. chim.*, 1921, **40**, 370) in that we found a fall in conductivity. This result was supported, however, by using 3 : 4 : 6-trimethyl α-*d*-mannose (Bott, Haworth, and Hirst, J., 1930, 1395), in which any possibility of combination with boric acid at positions other than those under investigation is precluded. An initial depression was observed, in harmony with the results for the methylated glucose derivatives, and in agreement with viscosity determinations, but this depression gradually became less, parallel with the mutarotation, which at once confirms our observation on β-mannose and agrees with the present conception of the structure of this sugar. It is noteworthy that the change in conductivity is relatively small (this depends on the proportion of α- and β-forms at equilibrium) and that the relatively high initial value as found for β-glucose is absent.

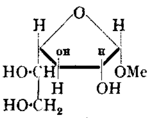
α-*l*-Rhamnose suffered an elevation of conductivity during mutarotation, which agrees with the view that the hydroxyl groups on C_1 and C_2 are *trans*-.

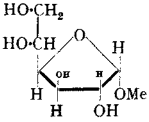
Striking results were obtained with furanosides: γ-methylgalactoside (I) showed a depression of conductivity (12 gemmhos) (cf. α-methylglucopyranoside), but γ-methylglucoside (II) gave an elevation of 110 and α-methylmannofuranoside (III) an elevation of 3350. (These results are for M/2-solutions.) The result for the galactofuranoside reveals that the $\cdot CH(OH)\cdot CH_2\cdot OH$ group alone has no positive influence on the conductivity in this case. By comparison with ethylene glycol, which shows a depression, this is only to be expected, since this group, being a side chain, is permitted complete

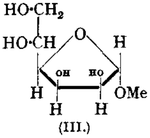
* All conductivities are subsequently given in terms of 10^{-6} mho.

freedom as to the relative positions of the hydroxyl groups, which will naturally incline to repel one another.

An examination of models, however, reveals that the glucofuranoside has a hydroxyl group in close proximity to the CH(OH)·CH_2·OH group, giving three hydroxyl residues near to one another. For the α-methylmannofuranoside we have two hydroxyl groups within easy reach of the CH(OH)·CH_2·OH group and on the same side of the ring plane.


(I.)


(II.)


(III.)

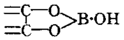
We thus have four hydroxyl groups as in erythritol, but here there is much less freedom of movement. In this case there is an accumulation of hydroxyl groups but the conditions are so complex that it is not yet possible to advance any definite hypothesis to account for the increase in conductivity.

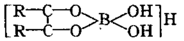
Comparable with the elevation given by α-methylmannofuranoside is that of a α-*l*-sorbose, *viz.*, 2159 gemmhos in M/2-solution (cf. Böeseken and Leefers, *Rec. trav. chim.*, 1935, **54**, 865, who found 230 for M/10-solution). β-*d*-Fructose also gives a considerable elevation (703 in M/2-solution), but an examination of the ring structures for these ketoses fails to reveal the reason for the great difference between them. The fact that sorbose does not mutarotate might suggest that this sugar exists in solution in the keto-form, but other evidence does not favour such a view, and the question must be postponed for further study.

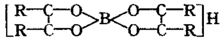
Rotation experiments have been carried out on α- and β-*d*-glucose, 3 : 4 : 6-trimethyl α-mannose, and α-methylmannofuranoside in both aqueous and boric acid solutions. No differences either in the equilibrium values or in the velocity of mutarotation were observed.

Consideration of the results for glycol, glycerol, erythritol, dulcitol, αβ-propylene glycol, and triethylene glycol shows that there is no very considerable increase in the conductivity of boric acid solution until four hydroxyl groups are present. Böeseken (*Rec. trav. chim.*, 1915, **34**, 96) showed that for pentaerythritol the elevation was about 6 times that observed for erythritol, and this appears to be due to the more rigid tetrahedral structure present in the former compound.

There has been some conflict of opinion as to whether or not the conductivity effects of polyhydroxy-compounds with boric acid are dependent on the formation of complexes (IV), as first proposed by van't Hoff, and since adopted by Böeseken and his co-workers. The extensive literature includes papers by Kolthoff (*Rec. trav. chim.*, 1925, **44**, 975), Bancroft and Davis (*J. Physical Chem.*, 1930, **34**, 2479), Henderson and Prentice (J., 1902, **81**, 658), Darmois (*J. Chim. physique*, 1926, **23**, 130, 649), Burgess and Hunter (J., 1929, 2838), Böeseken and Vermaas (*J. Physical Chem.*, 1931, **35**, 1477), Hermans (*Z. anorg. Chem.*, 1925, **142**, 83), and many others. The objections raised are chiefly based on the inability to isolate such complexes in the solid state from the highly conducting aqueous solutions. Nevertheless, Lowry (J., 1929, 2853) described a borotartaric acid, Hermans


(IV.)


(V.)


(VI.)

(*loc. cit.*) a disalicylboric acid, and Brigl and Grüner (*Annalen*, 1932, **495**, 60) a glucose diboric acid, although special conditions have to be used for the isolation of such derivatives. Hermans (*loc. cit.*) and Böeseken and Vermaas (*loc. cit.*) have suggested that the dissociable complexes may possess structures of the type (V) or (VI), according as

one or two molecules of the hydroxy-compound are involved. In aqueous solution, however, it seems unreasonable that definite anhydrides such as this should be formed, and it is much more probable that the cyclic structure containing the boron atom is formed by a co-ordination process. Any such hypothesis must account for the increase in conductivity. By a mechanism analogous to the formation of BF_3,NH_3, boric acid may react with water to form the necessarily weak acid $\overset{+}{H}[\overset{-}{B}(OH)_4]$. If then the hydroxyl groups become associated with hydrogen atoms of the organic hydroxyl residue by means of hydroxyl bonds (Bernal and Megaw, *Proc. Roy. Soc.*, 1935, **151**, *A*, 384), which have recently been shown to be present in pentaerythritol (Llewellyn, Cox, and Goodwin, this vol., p. 883), it follows that as the number of these hydroxyl bonds around the boric acid is increased the negative charge on the central boron atom will be decreased, thus increasing the ease with which the hydrogen ion may be lost.

Examination of the results for α-*d*-galactose and α-methylgalactopyranoside suggests that the *cis*-hydroxyl groups at C_3 and C_4, by comparison with α-methylglucoside, have no (or, in the latter case only a slight) effect on the conductivity of boric acid solution. Böeseken (*Rec. trav. chim.*, 1921, **40**, 558) showed that whereas *cis-cyclo*pentane-1 : 2-diol gave a marked increase in conductivity, yet *cis-cyclo*hexane-1 : 2-diol gave a decrease. This can be understood when it is considered that the *cyclo*pentane ring is flat and the hydroxyl groups are in the same plane, but if the *cyclo*hexane ring is strainless, then the adoption of one or other of the Sachse–Mohr forms results in changes of the relative positions of both *cis*- and *trans*-hydroxyl groups and the alteration of conformation may perhaps account for the altered behaviour with boric acid. This can easily be seen by reference to models, and it is hoped that further investigation will lead to information on the conformation of the pyranose ring in solution.

EXPERIMENTAL.

Conductivity Experiments.

The Pyrex-glass conductivity vessel was specially constructed so that less than 1 c.c. of solution sufficed to cover the plates; the *polished* platinum electrodes were carried by the ground-in stopper, contact with the atmosphere being thereby excluded. Platinised plates were less satisfactory than polished platinum, which gave a sharp minimum for the solutions of low conductivity investigated in these experiments. The bridge, which was calibrated before use, was of the cylindrical type, wound with 3·6 m. of wire and divided into 1000 equal divisions, readings being taken to 0·25 of a scale division. A small induction coil and telephone were used in the usual manner in conjunction with standard variable resistances. The cell constant (0·4378) was determined with N/50-potassium chloride in conjunction with platinised electrodes, and with N/500-potassium chloride with the polished electrodes; the conductivity water used throughout had a specific conductivity of 2×10^{-6} mho. A larger cell of the same type (capacity 2 c.c.) was employed in experiments where relatively large quantities of pure material were available. The measurements were carried out at $25° \pm 0·01°$, the solutions being made up with water at this temperature; the same apparatus was used throughout, so the results are strictly comparable. From considerations of space, complete lists of the readings are not included, but readings of the variation in conductivity at 5- and 10-minute intervals (unless the reading remained constant) were taken in all cases. κ_1, κ_2, and κ_3 refer respectively to the conductivity (in gemmhos) of an M/2-aqueous solution of the sugar or sugar derivative concerned, of the M/2-boric acid solution employed, and of a solution in M/2-boric acid of the sugar or sugar derivative at the same concentration.

α-d-*Glucose*.—α-*d*-Glucose was prepared according to Hudson and Dale (*J. Amer. Chem. Soc.*, 1917, **39**, 322). The specific conductivity was reduced by grinding with pyridine at room temperature, filtration, and precipitation and washing with alcohol. Solvent was finally removed *in a vacuum at 40°*: $[\alpha]_D^{20°} + 106°$ *in water (c, 3·0) (after 2 mins.)*.

$\kappa_1 = 11·5$; $\kappa_2 = 27·6$.

Time (mins.)	5	30	60	80	100	120
κ_3	96·3	89·8	86·0	84·7	83·8	83·3 (constant value).

Elevation of conductivity: 59·4 (initial value; by extrapolation); 44·2 (final value).

β-d-*Glucose*.—β-*d*-Glucose, prepared by Behrend's method (*Annalen*, **1907**, **353**, 107), was well washed with alcohol to remove pyridine, and the solvent removed as before: $[\alpha]_D^{20^\circ}$ + 19·5° in water (*c*, 1·0) (after 3 mins.).

$\kappa_1 = 8{\cdot}5$; $\kappa_2 = 28{\cdot}0$.

Time (mins.)	12	20	30	60	80	100
κ_3	66·6	68·3	70·0	73·1	74·1	75·0 (constant value).

Elevation of conductivity: 26·5 (initial value; by extrptn.); 38·5 (final value).

It will be noted that a difference exists between the final values—expressed as elevations of conductivity—for α- and β-glucose. Böeseken (*loc. cit.*) also found this to be the case. The same "gap" was found to occur if the α- and β-glucose solutions were allowed to come to equilibrium before the addition of boric acid.

α-d-*Galactose*.—Kerfoot's "pure" galactose was found to be almost entirely α-*d*-galactose, and after being washed with 90% ethyl alcohol it gave $[\alpha]_D^{20^\circ}$ + 137·8° in water (*c*, 1·3) (after 3 mins.).

$\kappa_1 = 23{\cdot}3$; $\kappa_2 = 27{\cdot}9$.

Time (mins.)	10	40	60	100
κ_3	78·4	74·4	73·1	72·2 (constant value).

Elevation of conductivity: 29·5 (initial; by extrptn.); 21·0 (final).

β-d-*Mannose*.—In aqueous solution six samples of mannose had a high conductivity, not reduced by recrystallisation: $[\alpha]_D^{15^\circ}$ − 17·0° in water (*c*, 3·0) (initial value), + 14·8° (final value).

$\kappa_1 = 78{\cdot}2$; $\kappa_2 = 28{\cdot}0$.

Time (mins.)	7	15	30	50
κ_3	105·8	104·9	104·1	103·8 (constant value).

Elevation of conductivity: 0·4 (initial; by extrptn.); − 2·4 (final).

α-l-*Rhamnose*.—Specimen from B.D.H. of high purity: $[\alpha]_D^{18^\circ}$ − 6·8° in water (*c*, 1·0) (after 3 mins.); + 9·0° (final value).

$\kappa_1 = 5{\cdot}2$; $\kappa_2 = 29{\cdot}0$.

Time (mins.)	5	100
κ_3	41·8	46·1 (constant value).

Elevation of conductivity: 7·5 (initial; by extrptn.); 11·9 (final).

Sucrose.—$[\alpha]_D^{20^\circ}$ + 66·4° in water (*c*, 3·0).

$\kappa_1 = 7{\cdot}8$; $\kappa_2 = 28{\cdot}9$; $\kappa_3 = 27{\cdot}2$. *Depression of conductivity*: 9·5 (constant value).

α-*Methylglucopyranoside*.—This was prepared according to Patterson and Robertson (J., 1929, 300), and after 5 recrystallisations from absolute alcohol had m. p. 167°, $[\alpha]_D^{20^\circ}$ + 159° in water (*c*, 3·0) (Found: OMe, 15·4. Calc. for $C_7H_{14}O_6$: OMe, 16·0%).

$\kappa_1 = 3{\cdot}9$; $\kappa_2 = 27{\cdot}9$; $\kappa_3 = 22{\cdot}5$. *Depression of conductivity*: 9·3.

α-*Methylgalactopyranoside*.—Prepared as above, this had m. p. 116°, $[\alpha]_D^{20^\circ}$ + 179° in water (*c*, 1·0) (Found: OMe, 15·9. Calc. for $C_7H_{14}O_6$: OMe, 16·0%).

$\kappa_1 = 12{\cdot}9$; $\kappa_2 = 27{\cdot}9$; $\kappa_3 = 36{\cdot}8$. *Depression of conductivity*: 4·0.

2 : 3 : 4 : 6-*Tetramethyl Glucose*.—This sugar was prepared by the method of West and Holden (*J. Amer. Chem. Soc.*, 1934, **56**, 930) and recrystallisation from light petroleum gave a product, m. p. 85—88° (Found: OMe, 51·5. Calc. for $C_{10}H_{20}O_6$: OMe, 52·5%); $\kappa_1 = 50$. By 5 distillations at 135° (bath temp.)/0·03 mm., a specimen of the glucopyranose was secured with m. p. 72°, $[\alpha]_D^{20^\circ}$ + 70·3° in water (*c*, 0·5) ⟶ + 79·8° (constant value).

$\kappa_1 = 7{\cdot}0$; $\kappa_2 = 27{\cdot}9$; $\kappa_3 = 20{\cdot}8$. *Depression of conductivity*: 14·1.

Tetramethyl Methylglucopyranoside.—West and Holden's method (*loc. cit.*) was employed, and the syrup distilled twice at 85°/0·04 mm. with a fractionating column; $n_D^{18^\circ}$ 1·4465 (Found: OMe, 60·5. Calc. for $C_{11}H_{22}O_6$: OMe, 62·0%).

$\kappa_1 = 12{\cdot}2$; $\kappa_2 = 27{\cdot}6$; $\kappa_3 = 21{\cdot}5$. *Depression of conductivity*: 18·3.

2 : 3 : 6-*Trimethyl Methylglucopyranoside*.—Starch was methylated according to Haworth, Hirst, and Webb (J., 1928, 2681) until the methoxyl content reached 44%. Hydrolysis by the method of Baird, Haworth, and Hirst (J., 1935, 1201) yielded a mixture of tri- and tetramethyl methylglucosides which were fractionated in a high vacuum, the first runnings being rejected. A colourless syrup, $n_D^{18°}$ 1·4550, was obtained (Found : OMe, 51·5. Calc. for $C_{10}H_{20}O_6$: OMe, 52·5%).

$\kappa_1 = 14{\cdot}1$; $\kappa_2 = 27{\cdot}6$; $\kappa_3 = 25{\cdot}5$. *Depression of conductivity* : 16·2.

2 : 3 : 6-*Trimethyl Glucopyranose*.—Hydrolysis of the corresponding methylglucoside by means of aqueous hydrochloric acid, followed by isolation in the usual way, yielded the sugar, after recrystallisation from ether, of m. p. 117° : $[\alpha]_D^{18°}$ + 66° in water (*c*, 1·4) (final value) (Found : OMe, 40·5. Calc. for $C_9H_{18}O_6$: OMe, 41·8%).

$\kappa_1 = 10{\cdot}4$; $\kappa_2 = 27{\cdot}9$; $\kappa_3 = 28{\cdot}8$. *Depression of conductivity* : 9·5.

3 : 4 : 6-*Trimethyl* α-d-*Mannose*.—Bott, Haworth, and Hirst's method (*loc. cit.*) was used. Care was necessary to keep the intermediate "γ"-tetra-acetyl methylmannoside from becoming even faintly acid, the addition of sodium bicarbonate being necessary to prevent this. The product (Found : C, 48·5; H, 8·1; OMe, 41·0. Calc. for $C_9H_{18}O_6$: C, 48·7; H, 8·1; OMe, 41·8%) had m. p. 104°, $[\alpha]_D^{20°}$ + 22° in water (*c*, 0·6) (initial value) falling to + 8·3° (constant value). The same results were obtained in boric acid solution.

$\kappa_1 = 18{\cdot}0$; $\kappa_2 = 27{\cdot}0$.

Time (mins.)	6	15	20	40	60	80
κ_3	34·8	36·4	37·2	39·4	40·3	40·9 (equilibrium value)

Depression of conductivity : 12·1 (initial), 4·1 (final).

Glucose Diethylmercaptal.—The product obtained by Fischer's method (*Ber.*, 1894, **27**, 673) was recrystallised repeatedly from water; m. p. 128°.

$\kappa_1 = 11{\cdot}7$; $\kappa_2 = 5{\cdot}1$; $\kappa_3 = 193{\cdot}0$. *Elevation of conductivity* : 176·2.

Ethylene Glycol.—$\kappa_1 = 4{\cdot}8$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 27{\cdot}1$. *Depression of conductivity* : 7·7.

Glycerol.—$\kappa_1 = 7{\cdot}2$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 45{\cdot}3$. *Elevation of conductivity* : 8·1.

αβ-*Propylene Glycol*.—$\kappa_1 = 16{\cdot}2$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 33{\cdot}5$. *Depression of conductivity* : 12·7.

Triethylene Glycol.—$\kappa_1 = 7{\cdot}6$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 23{\cdot}1$. *Depression of conductivity* : 14·5.

Erythritol.—$\kappa_1 = 25{\cdot}0$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 97{\cdot}0$. *Elevation of conductivity* : 42·0.

Dulcitol.—$\kappa_1 = 35{\cdot}9$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 660$. *Elevation of conductivity* : 594.

Mannitol.—$\kappa_1 = 12{\cdot}3$; $\kappa_2 = 29{\cdot}0$; $\kappa_3 = 667{\cdot}3$. *Elevation of conductivity* : 626.

γ-*Methylglucoside*.—Fischer's method (*Ber.*, 1914, **47**, 1984) was employed, and the product when distilled at 220° (bath temp.)/0·04 mm. had no action on Fehling's solution; $[\alpha]_D^{15°}$ − 14° in water (*c*, 5·0) (Found : OMe, 15·8. Calc. for $C_7H_{14}O_6$: OMe, 16·0%).

$\kappa_1 = 15{\cdot}0$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 156{\cdot}3$. *Elevation of conductivity* : 111·3.

γ-*Methylgalactoside*.—The method of Haworth, Ruell, and Westgarth (J., 1924, **125**, 2468) gave a non-reducing syrup, $[\alpha]_D^{18°}$ − 57·6° in water (*c*, 2·3) (Found : OMe, 15·1%). Comparison of the rate of hydrolysis in N/10-hydrochloric acid at 90° with that for α-methylgalactopyranoside showed that, whereas only 50% of the latter was hydrolysed during 9 hours, the furanoside was completely hydrolysed in 5 hours.

$\kappa_1 = 30{\cdot}0$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 48{\cdot}0$. *Depression of conductivity* : 12·0.

α-*Methylmannofuranoside*.—Haworth, Hirst, and Webb's method (J., 1930, 658) yielded a colourless, non-reducing syrup which crystallised immediately on nucleation with a crystal of the substance kindly provided by Professor Haworth; m. p. 119°; $[\alpha]_D^{18°}$ + 113° in water (*c*, 1·5), + 112·2° in M/2-boric acid (*c*, 0·5).

$\kappa_1 = 20{\cdot}0$; $\kappa_2 = 30{\cdot}0$; $\kappa_3 = 3400$. *Elevation of conductivity* : 3380.

β-d-*Fructose*.—Commercial fructose was purified by slow recrystallisation from absolute alcohol and washing with acetone; $[\alpha]_D^{17°}$ — 130° in water (c, 3·6).

$\kappa_1 = 28·6$; $\kappa_2 = 30·0$; $\kappa_3 = 762$. *Elevation of conductivity*: 703.

α-l-*Sorbose*.—M. p. 164—165°, $[\alpha]_D^{18°}$ — 43·5° in water (c, 1·0).

(i) $\kappa_1 = 24·8$; $\kappa_2 = 30·0$; $\kappa_3 = 2214$. *Elevation of conductivity*: 2159.

(ii) For M/10-solutions in each case: $\kappa_1 = 9·3$; $\kappa_2 = 5·1$; $\kappa_3 = 212$. *Elevation of conductivity*: 197·6.

Rotation Experiments.

α-d-*Glucose*.—The values of $[\alpha]_D^{20°}$ at time t (mins.) for (i) M/2-aqueous solution and (ii) M/2-solution in M/2-boric acid were:

t	5	30	60	140	220	280	∞
$[\alpha]_D^{20°}$ (i)	+108·2°	94·1°	82·6°	64·4°	57·6°	54·9°	52·7°
$[\alpha]_D^{20°}$ (ii)	+108·3°	94·0°	82·8°	64·8°	57·4°	54·7°	52·6°

Similar experiments were carried out with M/4- and M/8-solutions; the figures in each case showed the same rate of mutarotation in aqueous and boric acid solution and the equilibrium values only varied from 52·3° to 52·6°.

β-d-*Glucose*.—The data, expressed as above, are:

t	3	20	40	60	90	150	240	∞
$[\alpha]_D^{20°}$ (i)	+20·6°	25·7°	30·6°	34·6°	39·2°	44·7°	49·0°	52·2°
$[\alpha]_D^{20°}$ (ii)	+20·8°	25·8°	30·8°	34·8°	39·2°	44·7°	49·2°	52·3°

Viscosity Experiments.

The apparatus used was that described by Hornel and Butler (J., 1936, 1361); it required less than 1 c.c. of liquid for a determination, and the capillary was of such dimensions that approximately 100 seconds were required for water to pass between the fixed points. M/2-Solutions of the substances examined were made up in water and in boric acid solution; a weighed amount of solution was transferred to the apparatus, and its time of flow determined by means of a Venner stop-watch reading to 0·1 sec., the mean of several determinations at 25° ± 0·02° being taken as the result.

The relative viscosity η_r was calculated from $\eta_r = \eta'/\eta = \rho'T'/\rho T$, where η and η' are the viscosity coefficients of two liquids of densities ρ and ρ' and times of fall T and T'. The results are recorded in the following table, in which G denotes the weight (in g.) in the viscometer, and T the mean time of fall (in secs.).

Relative Viscosities.

	M/2-*Aqueous solutions.*			M/2-*Solutions in* M/2-*boric acid.*		
	G.	T.	η_r.	G.	T.	η_r.
(Conductivity water)	0·9445	102·5	1·000	—	—	—
α-*d*-Glucose	0·971	124·2	1·250	0·982	128·9	1·240
β-*d*-Glucose	0·973	124·3	1·250	0·983	129·4	1·245
α-Methylglucopyranoside	0·967	129·7	1·295	0·978	134·2	1·290
3 : 4 : 6-Trimethyl α-mannose	0·967	136·5	1·360	0·977	141·1	1·350
2 : 3 : 6-Trimethyl methylglucopyranoside	0·962	140·7	1·400	0·972	146·0	1·400
2 : 3 : 4 : 6-Tetramethyl glucose	0·962	139·5	1·390	0·973	145·4	1·390
2 : 3 : 4 : 6-Tetramethyl methylglucoside	0·966	142·2	1·420	0·976	148·0	1·415
Boric acid	0·959	106·4	1·050	—	—	—

As shown by the following table, Einstein's equation (*loc. cit.*), which can be modified to $\eta_{sp.}S/c = K$, is approximately obeyed, K having a mean value of 0·44 for the solutions in M/2-boric acid. Here $\eta_{sp.}$ is the specific viscosity, c the weight concentration of dissolved phase, S the density of dissolved phase calculated from a knowledge of the weight of substance taken, the volume of water used, and the weight of solution, and K should be constant for any one class of substance.

It will be noted that the relative viscosity increases with increase in molecular weight; this is analogous to the increasing depression of conductivity on the introduction of an

increasing number of methoxyl groups, and both these results are complementary to the above relation between viscosity and molecular volume.

Comparison of Viscosity with Volume of Dissolved Phase for M/2-*Aqueous Solutions.*

Dissolved phase.	$\eta_{sp.}$	c.	η_{sp}/c.	S.	$\eta_{sp.}S/c$.
α-*d*-Glucose	0·250	8·25	0·0303	1·552	0·46
β-*d*-Glucose	0·250	8·25	0·0303	1·552	0·46
α-Methylglucopyranoside	0·295	8·82	0·0335	1·386	0·48
3 : 4 : 6-Trimethyl α-mannose	0·360	9·98	0·0361	1·337	0·48
2 : 3 : 6-Trimethyl methylglucopyranoside	0·400	10·55	0·0379	1·242	0·47
2 : 3 : 4 : 6-Tetramethyl glucose	0·390	10·55	0·0370	1·242	0·46
2 : 3 : 4 : 6-Tetramethyl methylglucoside	0·420	11·10	0·0378	1·275	0·48

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404. *The Alkaloids of* Arundo Donax *L.*

By J. MADINAVEITIA.

From the leaves of *Arundo donax* L. a new alkaloid, $C_{12}H_{13}O_2N{\cdot}NMe$, has been isolated besides gramine (3-dimethylaminomethylindole). There are indications of the presence of a third alkaloid with phenolic properties.

Gramine reacting with methyl iodide in an alkaline medium undergoes a peculiar degradation, a quantitative yield of tetramethylammonium iodide and a substance $C_9H_8N{\cdot}OMe$ being obtained. The formation of a normal ethiodide takes place in the reaction of gramine with ethyl iodide in neutral solution, whereas tetramethylammonium iodide and trimethylamine are produced when methyl iodide is used.

FROM the leaves of the reed *Arundo donax* L., collected in Turkistan, Orékhov and Norkina (*Ber.*, 1935, **68**, 436) isolated an alkaloid $C_{11}H_{14}N_2$, for which they suggested the name donaxine. Von Euler, Erdtman, and Hellström (*Ber.*, 1936, **69**, 743) found donaxine to be identical with gramine, an alkaloid isolated by v. Euler *et al.* (*Z. physiol. Chem.*, 1935, **234**, 151; **235**, 37) from certain strains of barley. Gramine is 3-dimethylaminomethylindole and has been synthesised by Wieland and Chi Yi Hsing (*Annalen*, 1936, **526**, 188) and by Kühn and Stein (*Ber.*, 1937, **70**, 567). In addition to gramine, there has now been isolated from the leaves of *Arundo donax* L., collected in Catalonia, a small amount of another alkaloid, $C_{13}H_{16}O_2N_2$, for which the name *donaxarine* is suggested. Donaxarine shows a marked difference from gramine in its colour reactions. It gives no coloration when heated in acid solution with *p*-dimethylaminobenzaldehyde (Ehrlich's reagent) and the Hopkins–Cole test (glyoxylic reagent) is likewise negative; both reactions are positive in the case of gramine. The vapour of donaxarine gives the pine wood reaction, which is, however, not quite specific for indole derivatives. Donaxarine contains one *N*-methyl group and one active hydrogen atom, but no *O*-methyl and apparently no *C*-methyl group. It is optically inactive. By the Kuhn–Roth method no acetic acid was formed, whereas in a special experiment 0·5 equivalent of acetic acid was formed from physostigmine.

The presence of a third alkaloid with phenolic properties was indicated in the leaves of *Arundo donax* L., but it could not be obtained in a crystalline form. Analyses of the purest specimens showed large proportions of active hydrogen.

Before the synthesis of gramine by Wieland and Chi Yi Hsing (*loc. cit.*) had established its constitution, several attempts to degrade the alkaloid were made. Methyl iodide in an alkaline medium caused a peculiar degradation, resulting in a quantitative yield of tetramethylammonium iodide and a neutral substance $C_{10}H_{11}ON$ (Madinaveitia, *Nature*, 1937, **27**, 139). The latter is most likely *3-methoxymethylindole*, formed by hydrolytic removal of the methylated dimethylamino-group and methylation of the hydroxyl

compound thus remaining. The dimethylamino-group of gramine is rather labile; alkali *is not required for its hydrolysis. When gramine was allowed to react with methyl iodide in methyl-alcoholic solution, instead of the formation of the methiodide,* m. p. *176°, described by Orékhov and Norkina (loc. cit.),* evolution of trimethylamine, followed *by precipitation of tetramethylammonium iodide, was observed. Besides these two substances a water-insoluble compound that could not be crystallised was obtained;* presumably it is 3-*hydroxymethylindole,* which was prepared by catalytic reduction of indolealdehyde, showed very similar properties, but crystallised readily. The formation of tetramethylammonium iodide, which does not melt at 300°, in the reaction of gramine with methyl iodide may perhaps account for the unusually high melting point of the quaternary iodide prepared by Wieland and Chi Yi Hsing (*loc. cit.*) and Kühn and Stein (*loc. cit.*) in order to characterise their synthetic gramine and considered by them to be its methiodide.

Although no methiodide could be obtained from gramine, an *ethiodide* was readily formed by interaction of the alkaloid and ethyl iodide in acetone solution. When this reaction was carried out in alkaline medium, a neutral compound, $C_{11}H_{13}ON$, probably 3-*ethoxymethylindole*, was formed, as well as dimethylethylamine (identified by its picrate).

EXPERIMENTAL.

Isolation of the Alkaloids.—An alcoholic extract of *Arundo donax* leaves (50 kg.) was evaporated to 5 l. and the non-basic constituents were removed with ether (3 l.). The acid solution was made slightly alkaline with ammonia, and the alkaloids extracted with ether. The ethereal solution of the bases was thoroughly extracted with dilute hydrochloric acid, and the acid solution strongly basified with sodium hydroxide. Extraction of the alkaline solution removed the non-phenolic bases, the phenolic bases remaining in solution (solution A).

Gramine. The ethereal solution containing the non-phenolic bases was dried with sodium sulphate, and the ether removed on the water-bath; the oily residue partly crystallised on standing. The crystalline constituent, after successive recrystallisations from acetone, methyl ethyl ketone (two), benzene, light petroleum (b. p. 80—100°), and alcohol, had all the properties of gramine: m. p. 133°; perchlorate, m. p. 146°; picrate, m. p. 140°. Yield, 13·8 g. (0·028%).

Donaxarine and phenolic bases. Carbon dioxide was passed through solution A, a voluminous precipitate being formed. When all the sodium hydroxide had been converted into carbonate, the alkaloids were extracted with ether. The ethereal solution was extracted with 2N-sodium hydroxide to remove the phenolic constituents, dried with sodium sulphate, and evaporated on the water-bath; the oily residue partly crystallised on standing. After being recrystallised once from acetone and twice from methyl alcohol, it gave 60 mg. of *donaxarine,* m. p. 217° [Found: C, 67·6, 67·7; H, 7·1, 7·2; N, 12·5; *N*-Me, 7·85; *M* (Rast), 204. $C_{13}H_{16}O_2N_2$ requires C, 67·2; H, 6·9; N, 12·1; 1 *N*-Me, 6·5%; *M*, 232]. The substance contains 1·35 equivs. of active hydrogen.

The alkaline solution containing the phenolic bases was saturated with carbon dioxide and extracted with ether, and the phenolic constituents removed with sodium hydroxide: this procedure was repeated three times. The oil finally obtained separated from hot carbon tetrachloride in white amorphous flocks, m. p. 127—128°, which resinified on standing.

Reaction of Gramine with Methyl Iodide in an Alkaline Medium.—A solution of gramine (1 g.) in methyl alcohol (5 c.c.), made alkaline with 25% methyl-alcoholic potassium hydroxide (2·5 c.c.) and treated with methyl iodide (1 c.c.) in methyl alcohol (4 c.c.), soon became hot, a basic odour was noticed, and a crystalline precipitate began to form. After standing at 20° for 12 hours, this was collected, washed with methyl alcohol, and recrystallised from methyl alcohol, tetramethylammonium iodide (1·2 g.) being obtained, m. p. above 360° (Found: C, 24·1, 24·2; H, 6·1, 6·1; N, 5·9, 5·8; I, 62·7, 62·5. Calc. for $C_4H_{12}NI$: C, 23·9; H, 5·9; N, 6·9; I, 63·2%). The picrate had m. p. 310° (Found: C, 40·1; H, 4·9; N, 17·9. Calc.: C, 39·6; H, 4·9; N, 18·5%).

The alcoholic solution from which the tetramethylammonium iodide had crystallised was poured into water (*ca.* 100 c.c.). 3-*Methoxymethylindole* separated in platelets (0·8 g.). Recrystallised from light petroleum (b. p. 60—80°), it formed long white needles, m. p. 99—100° (Found: C, 74·9, 74·4; H, 6·9, 6·9; N, 9·1; *O*-Me, 18·0. $C_{10}H_{11}ON$ requires C, 74·5; H, 6·9; N, 8·7; 1 *O*-Me, 19·2%). It contained 1·13 active hydrogen atoms. No *N*-Me could

be detected. In another experiment the substance responsible for the basic odour in the early stages of the reaction was isolated as the picrate and proved to be trimethylamine.

Reaction of Gramine with Methyl Iodide in Methyl-alcoholic Solution.—To a solution of gramine (0·2 g.) in methyl alcohol (0·7 c.c.), methyl iodide (0·1 c.c.) was added. After 1 hour's standing at 20° a strong basic smell was noticed and a crystalline precipitate formed. Air was bubbled through the mixture and then through alcoholic picric acid; the crystalline picrate formed had m. p. 215—216° (trimethylamine picrate has m. p. 216°). When most of the trimethylamine had been eliminated, the precipitate was collected and recrystallised from methyl alcohol; it had m. p. above 300° and was converted into a picrate, m. p. 312° (tetramethylammonium picrate has m. p. 312—313°). The alcohol from which the tetramethylammonium iodide had separated was poured into water; the neutral amorphous precipitate became red on standing and was extremely sensitive to the action of acids.

Reduction of Indole-3-aldehyde.—The aldehyde (0·5 g.), dissolved in alcohol (70 c.c.), was shaken with Adams's catalyst (PtO_2) (0·1 g.) in an atmosphere of hydrogen. Absorption of 182 c.c. (calc., 164 c.c.) took place in 8 hours. The alcoholic solution was filtered, poured into water (*ca.* 100 c.c.), and extracted with ether. The ethereal solution was dried, and the greater part of the ether removed on the water-bath. On slow evaporation of the remainder *3-hydroxymethylindole* crystallised in platelets, m. p. 90°, unchanged by recrystallisation from benzene [Found: N, 9·4, 9·5; *M* (Rast), 157. C_9H_9ON requires N, 9·5%; *M*, 147].

Reaction of Gramine with Ethyl Iodide in an Alkaline Medium.—A solution of gramine (0·2 g.) in alcohol (1 c.c.), made alkaline with 25% alcoholic potassium hydroxide (0·5 c.c.) and treated with ethyl iodide (0·2 c.c.), developed a basic odour after 1 hour. Air was bubbled through the solution and then into alcoholic picric acid; the reaction was complete in 12 hours and the crystalline picrate obtained had m. p. 204° (dimethylethylamine picrate has m. p. 194°). Addition of water to the residual solution precipitated *3-ethoxymethylindole*, m. p. 93—94° after recrystallisation from light petroleum (b. p. 60—80°) (Found: C, 75·3, 75·1; H, 8·0, 8·0; N, 8·4. $C_{11}H_{13}ON$ requires C, 75·4; H, 7·4; N, 8·0%).

Gramine Ethiodide.—Gramine (0·2 g.), dissolved in acetone (5 c.c.), was mixed with ethyl iodide (0·3 c.c.) and after 36 hours the crystals obtained were recrystallised from alcohol, giving white prisms, m. p. 176° (Found: C, 47·2; H, 5·2; N, 8·7. $C_{13}H_{19}N_2I$ requires C, 47·3; H, 5·6; N, 8·5%).

The author is indebted to the Moray Fund of Edinburgh University for a grant and to Messrs. Duncan Flockhart and Co. for the extraction of the material. He also thanks Prof. G. Barger for his suggestions and interest and Miss A. Jacob for her help in some of the experiments.

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405. *The Lability of the Dimethylamino-group in Some Dimethylamino-ketones.*

By (MISS) A. JACOB and J. MADINAVEITIA.

The lability of the dimethylamino-group in ω-dimethylaminoacetophenone and β-dimethylaminopropiophenone results in the formation of trimethylamine when these ketones are treated with methyl iodide in an alkaline medium. It also leads to the formation of abnormal products when they react with phenylhydrazine, *viz.*, the osazone of phenylglyoxal from the former and 1 : 3-diphenylpyrazoline from the latter. β-Dimethylaminoethyl methyl ketone reacting with phenylhydrazine forms 1-phenyl-3-methylpyrazoline. The reaction of these ketones with hydrazine is more complicated.

THE alkaloid gramine (3-dimethylaminomethylindole), treated with methyl iodide in an alkaline medium, loses the dimethylamino-group and gives a compound, $C_{10}H_{11}ON$, which is probably 3-methoxymethylindole (see preceding paper). In order to find an analogous reaction some tertiary amines have been treated with methyl iodide under similar conditions.

ω-Dimethylaminoacetophenone forms with methyl iodide in a neutral medium the methiodide of the base. When the reaction is carried out in the presence of methyl-alcoholic potassium hydroxide, trimethylamine is formed; the only other product isolated is benzoic acid. ω-Dimethylaminoacetophenone methiodide, treated with alkali, yields the same products (*cf.* Rumpel, *Arch. Pharm.*, 1899, **237**, 225). β-Dimethylaminopropiophenone and methyl iodide in neutral solution also give the methiodide, but when the reaction is carried out in the presence of methyl-alcoholic potassium hydroxide trimethylamine and a nitrogen-free compound ($C_{18}H_{16}O_2$) are formed. The latter is probably 1 : 2-dibenzoyl*cyclo*butane, conceivably formed by the condensation of two molecules of phenyl vinyl ketone originating from the Hofmann degradation of the quaternary salt. β-Dimethylaminoethyl methyl ketone, reacting in methyl-alcoholic potassium hydroxide with methyl iodide, forms tetramethylammonium iodide and presumably vinyl methyl ketone (cf. Robinson, this vol., p. 53).

The reaction of ω-dimethylaminoacetophenone with phenylhydrazine also shows the lability of the dimethylamino-group: in 50% acetic acid solution, the osazone of phenylglyoxal is formed. The same substance has been obtained in a similar way from ω-aminoacetophenone. This reaction resembles the formation of glyoxalosazone from aminoacetaldehyde and phenylhydrazine (Fischer, *Ber.*, 1893, **26**, 95) and of methylglyoxalosazone from phenylhydrazine and aminoacetone (Gabriel and Pinkus, *ibid.*, p. 2202). Treatment of β-dimethylaminopropiophenone with phenylhydrazine in 50% acetic acid solution yields 1 : 3-diphenylpyrazoline (Auwers, *Ber.*, 1932, **65**, 833). Similarly, formation of 1-phenyl-3-methylpyrazoline takes place in the reaction between β-dimethylaminoethyl-methyl ketone and phenylhydrazine.

The reaction of ω-dimethylaminoacetophenone with hydrazine in 50% acetic acid solution is more complicated. The *compound* obtained has the formula $C_{16}H_{16}N_6$. β-Dimethylaminopropiophenone and hydrazine in acetic acid solution give a crystalline yellow *substance*, $(C_6H_6N)_n$, m. p. 141°.

EXPERIMENTAL.

Action of Methyl Iodide and Potassium Hydroxide on ω-Dimethylaminoacetophenone.—The ketone (3 g.) (Stevens, Cowan, and MacKinnon, J., 1931, 2570) was dissolved in methyl alcohol (15 c.c.) and mixed with methyl iodide (3 c.c.) and 25% methyl-alcoholic potassium hydroxide (40 c.c.). After 1—2 days' standing at 37° a strong basic smell was noticed. Air was bubbled through the alcoholic solution and passed into alcoholic picric acid. The crystalline picrate obtained, after recrystallisation from alcohol, proved to be trimethylamine picrate, m. p. and mixed m. p. 216°. The methyl-alcoholic solution was then poured into water (*ca.* 300 c.c.), acidified with dilute hydrochloric acid, and extracted with ether. After being dried with sodium sulphate, the ether was removed on the water-bath; the residue separated from light petroleum (b. p. 60—80°) in crystals of benzoic acid, m. p. and mixed m. p. 121°.

ω-Dimethylaminoacetophenone methiodide was treated under the same conditions with methyl-alcoholic potassium hydroxide only; trimethylamine and benzoic acid were again formed.

Action of Methyl Iodide and Potassium Hydroxide on β-Dimethylaminopropiophenone.—The procedure was that described above [β-dimethylaminopropiophenone (Mannich and Heilner, *Ber.*, 1922, **55**, 356) 3 g., methyl alcohol 15 c.c.; 25% methyl-alcoholic potassium hydroxide 40 c.c., methyl iodide 4 c.c.]. Trimethylamine picrate, m. p. 215—216°, was obtained. The oily residue left on evaporation of the ethereal extract partly crystallised on cooling. Repeated crystallisation from carbon tetrachloride gave 0·6 g. of a *substance*, m. p. 172° [Found: C, 81·5, 81·6; H, 6·0, 6·1; *M* (Rast), 290. $(C_9H_8O)_2$ requires C, 81·8; H, 6·0%; *M*, 264], very soluble in alcohol, acetone, chloroform and ethyl acetate.

β-Dimethylaminopropiophenone methiodide, treated in the same way with methyl-alcoholic potassium hydroxide alone, gave the same two products.

Action of Methyl Iodide and Potassium Hydroxide on β-Dimethylaminoethyl Methyl Ketone.—Methyl-alcoholic potassium hydroxide (5 c.c.) and methyl iodide (20 drops) were added to a solution of 0·2 c.c. of β-dimethylaminoethyl methyl ketone (Mannich, *Arch. Pharm.*, 1917, **255**, 1566) in methyl alcohol (0·5 c.c.). After 1 hour a crystalline precipitate formed, m. p. above 340°. A small amount of this compound was dissolved in hot alcohol, and alcoholic picric acid added; the solution after concentration deposited long hairy needles, m. p. 290° (tetramethylammonium picrate has m. p. 312—313°).

Phenylhydrazine and ω-Dimethylaminoacetophenone.—The ketone (2 g.) and phenylhydrazine (3 c.c.) were dissolved in 50% acetic acid (20 c.c.) and heated on the water-bath; after 10 minutes a yellow solid separated. After 1 hour's heating, the mixture was poured into water, and the crystalline precipitate collected. Repeated crystallisation from alcohol gave yellow needles of the phenylosazone of phenylglyoxal, m. p. 155° (Found: N, 17·9. Calc. for $C_{20}H_{18}N_4$: N, 17·8%). The same osazone was obtained when aminoacetophenone hydrochloride (2 g.), dissolved in 50% acetic acid (20 c.c.), and phenylhydrazine (2 c.c.) were heated for ½ hour on the water-bath; the thick oil separating soon solidified. After being washed with water and recrystallised several times from alcohol, it had m. p. 155°.

Phenylhydrazine and β-Dimethylaminopropiophenone.—β-Dimethylaminopropiophenone hydrochloride (3 g.), sodium acetate (3 g.), and phenylhydrazine (3 g.) were dissolved in 50% acetic acid (30 c.c.) and heated on the water-bath for 1—2 hours. The clear solution soon became turbid and a thick oil separated, which crystallised on cooling. The mixture was poured into water (*ca.* 300 c.c.) and the solid was washed with water and recrystallised three times from alcohol, giving colourless crystals (1·5 g.), m. p. 151°, of 1 : 3-diphenylpyrazoline (Found: C, 81·1; H, 6·4; N, 12·8. Calc. for $C_{15}H_4N_2$: C, 81·1; H, 6·4; N, 12·6%).

Phenylhydrazine and β-Dimethylaminoethyl Methyl Ketone.—The ketone (2 c.c.) and phenylhydrazine (4 c.c.), treated as described above, gave a solid. This was dissolved in the minimum amount of alcohol, an equal volume of saturated alcoholic hydrogen chloride added, and the mixture refluxed for 2 hours on the water-bath. On cooling, a crystalline solid appeared. The product was poured into water and made alkaline with sodium hydroxide. After 12 hours a crystalline substance separated, which, recrystallised once from alcohol and twice from light petroleum (b. p. 60—80°), gave 1-phenyl-3-methylpyrazoline, m. p. 73° (Found: C, 74·8; H, 7·4; N, 17·6. Calc. for $C_{10}H_{12}N_2$: C 75·0; H, 7·6; N, 17·5%).

Hydrazine and ω-Dimethylaminoacetophenone.—The ketone (1 g.) and hydrazine hydrate (50% solution) (5 c.c.) were mixed with 70% acetic acid (10 c.c.) and heated on the water-bath for ½ hour. The thick oil obtained solidified on addition of water, and after two recrystallisations from alcohol colourless crystals, m. p. 206°, were obtained [Found: C 66·3; H, 5·4; N, 28·8; *M* (Rast), 258. $C_{16}H_{16}N_6$ requires C, 66·5; H, 5·5; N, 28·8%; *M*, 290].

Hydrazine and β-Dimethylaminopropiophenone.—The ketone hydrochloride (2 g.) and sodium acetate (2 g.) were dissolved in water (5 c.c.) and mixed with hydrazine hydrate (50% solution) (7 c.c.) and acetic acid (70%) (10 c.c.). After the treatment described above, the *product* was obtained in pale yellow needles, m. p. 141° [Found: C, 78·5; H, 6·6; N, 14·9; *M* (Rast), 93. C_6H_6N requires C, 78·2; H, 6·5; N, 15·2%; *M*, 92]. In spite of the molecular weight the substance seems to be a polymer.

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406. *Dehydrodi-2-hydroxy-1-naphthylmethane.*

By Edwin A. Shearing and Samuel Smiles.

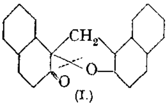
The structures assigned by previous investigators to dehydrodi-2-hydroxy-1-naphthylmethane are examined. It is shown that the substance has the quinolic ring structure suggested by Pummerer and Cherbuliez, the relations between it and the monoalkali derivatives of di-2-hydroxynaphthylmethane being thus elucidated. The formation of dehydro-compounds and covalent monoalkali derivatives from substituted di-2-hydroxyphenylmethanes is demonstrated and evidence is offered that the formation of these is controlled by conditions of substitution similar to those observed with the derivatives of di-2-hydroxyphenyl sulphide. Further investigation has shown the existence of dehydro-compounds of "mixed" type as required by theory.

Abel (*Ber.*, 1892, **25**, 3482) found that mild alkaline oxidation converts di-2-hydroxy-1-naphthylmethane into a dehydro-derivative by removal of two hydrogen atoms. He regarded the product as a peroxide, but Pummerer and Cherbuliez, having shown (*Ber.*, 1914, **47**, 2957) that it yields a monophenylhydrazone and recognising the analogy between it and bimolecular dehydrophenols such as dehydro-1-methyl-2-naphthol,

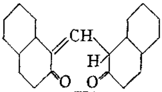
assigned to it the structure (I). More recently Kohn and Ostersetzer (Monatsh., 1918, 39, 299) and Kohn and Schwarz (ibid., 1925, 46, 273) have advocated for this substance the structure (II) or the tautomeric form; and Dischendorfer (Ber., 1926, 59, 774), regarding (II) as more probably correct than (I), has employed it as a basis for explaining the formation of dibenzacridone during the reaction of the substance with hydroxylamine and later with his colleagues has applied this type of structure (II) to other members of the group (*Monatsh.*, 1927, **48**, 545). A decision between these structures was desired mainly on account of the relationship of the substance to the covalent alkali derivatives of di-2-hydroxy-1-naphthylmethane, which are converted into it by oxidation, and also because it gave promise of serving as a useful source of unsymmetrical derivatives of the series.

Dehydrodi-2-hydroxy-1-naphthyl sulphide is known (J., 1930, 959, 1740) to have a structure analogous to (I) (S instead of CH_2). In their modes of formation and in much of their chemistry the dehydro-methane and dehydro-sulphide show close similarity. For example, it is now shown that the adduct formed from bromine and the dehydro-methane yields after loss of hydrogen bromide a monobromo-derivative which evidently contains the halogen in the 3-position of the quinonoid nucleus, since it does not form a phenylhydrazone and on reduction yields 3-bromodi-2-hydroxy-1-naphthylmethane. Similar behaviour has been recorded with the dehydro-sulphide (J., 1932, 638). Also the two dehydro-derivatives behave similarly on nitration (J., 1914, **105**, 1746).

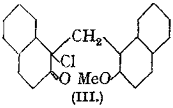
The two series of dehydro-compounds differ notably in their behaviour on reduction and on treatment with acetyl halides. In the sulphide series reduction with zinc and acetic acid yields the "*iso*sulphide," whilst acetic anhydride and acetyl halides lead to "*iso*"-dinaphthathioxins; these products are known to contain the 1 : 2′-dinaphthyl oxide group (J., 1930, 959; 1931, 719). On the other hand, dehydrodi-2-hydroxy-1-naphthylmethane and its derivatives are converted by zinc and acetic acid into the



(I.)



(II.)



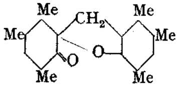
(III.)

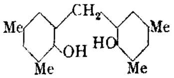
di-2-hydroxynaphthylmethanes from which they have been prepared (compare also Pummerer and Cherbuliez, *loc. cit.*) and it is also now shown that acetyl chloride and acetic anhydride are without action on the dehydro-methanes under conditions which are effective with the dehydro-sulphides, whilst acetyl iodide yields the di-2-acetoxynaphthylmethanes. This different behaviour of the two series of dehydro-compounds cannot be effectively used for the rejection of (I) and the acceptance of (II) for the dehydro-methanes. It is evident that reduction of the quinolic system of the dehydro-sulphide (I, S instead of CH_2) leads to fission of the less stable ⁝C–S· linkage therein, leaving the 1 : 2′-oxide group intact (J., 1930, 959); on the other hand, reduction of this system in a substance of type (I) may be expected to leave the more stable ⁝C–CH_2· group intact, the now less stable 1 : 2′-oxide group being ruptured as indicated (I). From this point of view the different results of reduction in the two series are seen to be due to different stability relations in the respective quinolic ring systems. Also it may be noted that the relative activities of the two dehydro-compounds with acetyl chloride and acetic anhydride accord with the greater stability of the quinolic ring in the dehydro-methane. In fact (I) satisfactorily expresses the known behaviour of dehydrodi-2-hydroxy-1-naphthylmethane and its relationship to the dehydro-sulphide.

The structure (II) is inadequate. Attempts to methylate or acylate the substance failed and it did not liberate methane from methylmagnesium iodide. Moreover, whilst sodium di-2-hydroxynaphthylmethane is smoothly converted into the dehydro-compound by hypochlorite, the monomethyl ether (this vol., p. 727) with this reagent yields a stable *chloro*-derivative to which the structure (III) must be assigned, since the substance is insoluble in aqueous alkali and the halogen is removed by zinc in cold acetic acid (Fries

and Engel, *Annalen*, 1924, **439**, 232), the monomethyl ether being regenerated. Bromine yielded a corresponding *derivative* and the monoacetyl derivative of di-2-hydroxynaphthylmethane behaved similarly (III, CH_3·CO and Br instead of Me and Cl respectively), the product being converted by hydrogen chloride into the 6-bromo-derivative (compare Fries and Engel, *loc. cit.*). The monoacetyl derivative was unstable in presence of alcoholic hypochlorite, the dehydro-derivative being formed with loss of acetyl. From these results it is concluded that the conversion of the dihydroxy-methane into the dehydro-derivative involves the removal of both mobile hydrogen atoms of the naphthol nuclei and that the methylene group is not directly concerned as required by (II). In fact (I) is fully justified and (II) must be rejected on account of its incompatibility with the behaviour of the substance and with the mechanism of its formation. Bromine converts di-2-hydroxy-1-naphthylmethane into the dehydro-derivative; this circumstance together with the results of the action of the halogen with the monomethyl ether and monoacetyl derivatives suggests that the quinolic ring in the product is formed by loss of halogen from an intermediate of type (III) (OH instead of OMe).

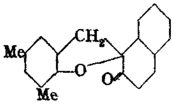
It has been recently shown (this vol., p. 1018) that di-*o*-hydroxy-sulphides of the benzene series which have no substituent in the 6-position yield neither covalent monoalkali derivatives nor simple dehydro-compounds and are thus sharply distinguished from those containing the 6-methyl group, which yield both series of derivatives. The explanation given (*loc. cit.*) to these relations was based on a structure of type (I) (S instead of CH_2) for the dehydro-sulphides. All the dehydro-compounds and covalent monoalkali derivatives of the methane series hitherto known are derived from 2-naphthol, but it is evident that those of the benzene series should be capable of existence and their formation may be expected to be controlled by conditions of substitution similar to those observed with the sulphides. Experimental support for this conclusion has been obtained. For example, whilst the ψ-cumenol derivative (compare IV) yielded the

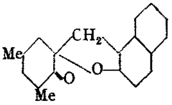
(IV.) 

 (V.)

unimolecular dehydro-derivative (IV) and the corresponding covalent monosodium compound (this vol., p. 1018; XVI, CH_2 instead of S), the *m*-4-xylenol derivative (V), which is devoid of the 6-methyl, gave neither of these characteristic products. In fact the relations between these two methane derivatives are closely similar to those existing between the corresponding sulphides.

According to the type of structure now adopted (for example, I and IV) for the dehydro-derivatives of the methane series, only one of the hydroxylated nuclei in the generator is required to assume the ketonic condition during oxidation; the existence of derivatives such as (VI) is therefore to be expected. Support for this structure, assigned to the oxidation product of 1-(2′-hydroxy-3′ : 5′-dimethylbenzyl)-2-naphthol (this vol., p. 1349; IV), is afforded by the fact that the substance readily yields a phenylhydrazone and therefore does not contain the ortho-substitution in the quinolic nucleus which is required by the alternative (VII).

(VI.) 

 (VII.)

Covalent monosodium derivatives have been obtained from 3-bromodi-2-hydroxy-1-naphthylmethane and from di-2-hydroxy-3 : 5 : 6-trimethylphenylmethane. These, isolated from aqueous media, contain various multiples of $2H_2O$; their stability and that of analogous hydrates is being investigated.

EXPERIMENTAL.

Dehydrodi-2-hydroxy-1-naphthylmethane.—(a) A solution of di-2-hydroxy-1-naphthylmethane (15 g.) in warm 2N-sodium hydroxide (50 c.c.) was added to a cooled and stirred solution of sodium hypochlorite (300 c.c., 2%). After being washed with warm alcohol the insoluble product was purified from aqueous acetone (10 g., m. p. 172°). (b) Bromine (1·3 c.c.) was slowly added to a cooled and stirred suspension of di-2-hydroxy-1-naphthylmethane (7·5 g.) in acetic acid (150 c.c.) which contained sodium acetate (7·5 g.). The product was isolated by dilution of the solution and was purified as described (5 g.). The dehydro-compound was recovered after its solution in acetic anhydride (5 hrs.) or in a mixture of acetic anhydride and acetyl chloride (40 hrs.) had been boiled. It was also recovered after the solution in acetyl chloride had been heated (5 hrs., 120°).

Reaction with acetyl iodide. A solution of acetyl iodide (1 g.) in acetic anhydride (5 c.c.) was slowly added (0°) to a suspension of the dehydro-compound in the latter solvent. Subsequently (1 hr.) the mixture was added to water containing sulphurous acid. After purification the product was identified as di-2-acetoxy-1-naphthylmethane (m. p. 213°) in the usual manner.

Reaction with toluene-4-sulphinic acid. A suspension of the dehydro-derivative (6 g.) in acetone (20 c.c.) was added to an aqueous solution (200 c.c.) of the potassium sulphinate (6 g.) containing sulphuric acid (60%, 10 c.c.). The mixture was shaken (12 hrs.) and then set aside (3 days); the insoluble *product*, purified from aqueous acetone, had m. p. 139—140° (decomp.) (Found: C, 73·7; H, 4·8; S, 6·8. $C_{28}H_{22}O_4S$ requires C, 74·0; H, 4·8; S, 7·0%). The structure of this additive product is at present uncertain, but it may be noted that it is resolved into the components by 2N-alkali hydroxide (15°).

Nitration. Nitric acid (1·3 c.c., *d* 1·4) was added slowly to a stirred suspension of the dehydro-compound (6 g.) in acetic anhydride. After all had dissolved, the mixture was added to warm water (500 c.c.). The product was purified from acetic anhydride (charcoal) and then from aqueous acetone (4·6 g.). 4(?)-*Nitrodehydrodi-2-hydroxy-1-naphthylmethane* formed bright yellow plates, m. p. 166° (Found: C, 73·3; H, 4·0. $C_{21}H_{13}O_4N$ requires C, 73·5; H, 3·8%), and gave a *phenylhydrazone* which separated from benzene in yellow plates, m. p. 191° (decomp.) (Found: N, 9·6. $C_{27}H_{19}O_3N_3$ requires N, 9·7%).

Reaction with methylmagnesium iodide. A solution of the reagent (2 mols.) in ether was added to a solution of the dehydro-compound (1 mol.) in dry benzene. Interaction took place with rise of temperature, but the liberation of methane was not detected. The product, obtained from the benzene solution after treatment with dilute sulphuric acid, was purified from aqueous alcohol; it formed small prisms, m. p. 135° (Found: C, 83·9; H, 5·7. Calc. for $C_{22}H_{18}O_2$: C, 84·0; H, 5·8%), their composition being the same as that recorded by Kohn and Ostersetzer (*loc. cit.*). It was different from the isomeric monomethyl ether of di-2-hydroxy-1-naphthylmethane, m. p. 142° (Evans and Smiles, *loc. cit.*), and was not attacked by zinc dust and acetic acid. It may be noted that the monomethyl ether in question liberated methane from methylmagnesium iodide.

Reaction with bromine. Bromine (3·2 g.) was slowly added to a cooled and stirred suspension of the dehydro-compound (6 g.) in acetic acid (40 c.c.). The colourless material which separated (30 mins.) was washed with water and purified from cold aqueous acetone. *Dehydrodi-2-hydroxy-1-naphthylmethane* 3 : 4-*dibromide* formed prisms, m. p. 148° (decomp.) (Found: C, 54·6; H, 3·2. $C_{21}H_{14}O_2Br_2$ requires C, 55·0; H, 3·1%).

3-*Bromodehydrodi-2-hydroxy-1-naphthylmethane* was obtained from the purified dibromo-additive product by treatment with warm pyridine. After the base had been removed by excess of dilute mineral acid, the insoluble product was washed with ether and purified from aqueous acetone; it formed orange prisms, m. p. 136° (Found: C, 66·8; H, 3·6. $C_{21}H_{13}O_2Br$ requires C, 66·8; H, 3·45%), which did not yield a phenylhydrazone. When zinc dust was added to its solution in hot acetic acid (5 g. in 50 c.c.) until the latter became colourless, a sparingly soluble zinc derivative separated. 3-Bromodi-2-hydroxy-1-naphthylmethane (4·5 g.) was liberated from this by dilute mineral acid; it had m. p. 201° (decomp.) (Found: C, 66·3; H, 4·1. Calc.: C, 66·6; H, 4·0%), and was identical with a sample prepared by synthesis (this vol., p. 1350). Oxidation of the latter in alkaline solution with hypochlorite gave a mixture of dehydro-derivatives which could not be effectively resolved (compare J., 1932, 637 for the behaviour of the corresponding sulphide).

Di-6-bromo-2-hydroxy-1-naphthylmethane.—Formaldehyde (4 c.c., 40%) was added to a stirred solution of 6-bromo-2-naphthol (18 g.) in acetic acid (125 c.c.) which contained

concentrated hydrochloric acid (8 c.c.). The insoluble *product* (15 g.) was purified from amyl alcohol and formed needles, m. p. 242° (decomp.) (Found : C, 54·9 ; H, 3·3. $C_{21}H_{14}O_2Br_2$ requires C, 55·0 ; H, 3·1%). The *diacetyl* derivative had m. p. 287° (Found : C, 55·2 ; H, 3·4. $C_{25}H_{18}O_4Br_2$ requires C, 55·3 ; H, 3·5%). The covalent sodium derivative separated in an amorphous state when a solution in warm aqueous sodium hydroxide was cooled ; it was soluble in ether and in hot benzene.

Dehydrodi-6-bromo-2-hydroxy-1-naphthylmethane was obtained by oxidising the corresponding hydroxy-derivative with aqueous hypochlorite in the usual manner. The crude material was washed with warm alcohol before purification from aqueous acetone. It formed yellow prisms, m. p. 209° (Found: C, 55·5 ; H, 2·8. $C_{21}H_{12}O_2Br_2$ requires C, 55·3 ; H, 2·6%), and gave a *phenylhydrazone* which separated from acetic acid as a yellow crystalline powder, m. p. 200° (Found : C, 59·1 ; H, 3·5. $C_{27}H_{18}ON_2Br_2$ requires C, 59·3 ; H, 3·3%). When submitted to the usual treatment with a cold solution of acetyl iodide in acetic anhydride, this dehydro-derivative yielded di-6-bromo-2-acetoxy-1-naphthylmethane, m. p. 287°, identical with an authentic sample.

Di-3-bromo-2-hydroxy-1-naphthylmethane was obtained from 3-bromo-2-naphthol and formaldehyde in the usual manner. It separated slowly from the reacting mixture and after purification from acetic acid formed tufts of needles, m. p. 207° (Found : C, 55·0 ; H, 3·3. $C_{21}H_{14}O_2Br_2$ requires C, 55·0 ; H, 3·1%).

Dehydrodi-3-bromo-2-hydroxy-1-naphthylmethane was prepared from this hydroxy-derivative by treatment with alkaline hypochlorite in the usual manner. It separated from benzene in yellow prisms, m. p. 232° (Found : C, 55·5 ; H, 2·6. $C_{21}H_{12}O_2Br_2$ requires C, 55·3 ; H, 2·6%), which did not yield a phenylhydrazone.

1'-Chloro-2'-keto-2-methoxy-1' : 2'-dihydrodi-1-naphthylmethane (III).—Aqueous sodium hypochlorite (30 c.c., 6%) was added to a stirred solution of the monomethyl ether of di-2-hydroxy-1-naphthylmethane (6 g.) in warm alcohol (50 c.c.) and aqueous sodium hydroxide (20 c.c., 2N). The insoluble *product*, after purification from cold aqueous acetone and subsequently from alcohol, formed yellow prisms (4 g.), which had m. p. 147° and became red on exposure to light (Found : C, 75·5 ; H, 4·8 ; Cl, 10·3 ; *M*, 343. $C_{22}H_{17}O_2Cl$ requires C, 75·7 ; H, 4·8 ; Cl, 10·2% ; *M*, 348·5). When zinc dust was added to a cold solution of the substance in acetic acid which contained a little hydrochloric acid, the colour was rapidly discharged ; dilution then yielded the monomethyl ether of di-2-hydroxy-1-naphthylmethane, m. p. 142°, which was identified as usual.

1'-Bromo-2'-keto-2-methoxy-1' : 2'-dihydrodi-1-naphthylmethane (III, Cl replaced by Br).—Bromine (1·3 c.c.) was slowly added to a cooled and stirred suspension of the monomethyl ether (7·8 g.) in acetic acid (100 c.c.) which contained sodium acetate (7 g.). The *product* separated as an amorphous yellow mass ; it was dried, and after purification from benzene or from cold aqueous acetone formed yellow needles (5·5 g.), m. p. 155°, which were decomposed by light (Found : C, 67·0 ; H, 4·3. $C_{22}H_{17}O_2Br$ requires C, 67·2 ; H, 4·3%). Reduction with zinc dust in a cold mixture of acetic and hydrochloric acids yielded the monomethyl ether of di-2-hydroxy-1-naphthylmethane.

The *monoacetyl* derivative of di-2-hydroxy-1-naphthylmethane, required for the preparation of the following keto-bromide, was obtained by slowly adding finely divided monosodium di-2-hydroxy-1-naphthylmethane tetrahydrate (20 g. ; this vol., p. 729) to cooled (0°) and stirred acetic anhydride (70 c.c.). It separated (15 g.) from the reacting mixture in the crystalline state and, purified from acetone, formed needles, m. p. 195° (Found : C, 80·5 ; H, 5·4. $C_{23}H_{18}O_3$ requires C, 80·7 ; H, 5·3%).

1'-Bromo-2'-keto-2-acetoxy-1' : 2'-dihydrodi-1-naphthylmethane.—Bromine (1·1 c.c.) was slowly added to a cooled and stirred suspension of the above acetyl derivative (6·8 g.) in acetic acid (120 c.c.) which contained sodium acetate (5·6 g.). After continued stirring (15 mins.) the insoluble matter was removed, the solution diluted with water (120 c.c.), and the impure product which separated washed with alcohol and purified from cold aqueous acetone (yield, 3 g.). It formed yellow prisms, m. p. 127° (decomp.) (Found : C, 65·6 ; H, 4·0. $C_{23}H_{17}O_3Br$ requires C, 65·5 ; H, 4·0%), which after reduction with zinc dust in cold acetic acid yielded the monoacetyl derivative of di-2-hydroxy-1-naphthylmethane.

Reaction with hydrogen chloride. After a solution of the keto-bromide (5 g.) in acetic acid (50 c.c.) saturated with hydrogen chloride had been kept (3 days), it was diluted (50 c.c. of water). The impure red material which separated was submitted to alkaline hydrolysis, the deacetylated product being liberated from the solution thus obtained. This, after repeated purification from aqueous alcohol (charcoal), was identified as 6-bromodi-2-hydroxy-1-

naphthylmethane (1·5 g.), m. p. 207°, by comparison with a synthetic specimen (this vol., p. 1350). Attempts to obtain a corresponding keto-chloride were made by adding aqueous alkaline hypochlorite to a cold suspension of the monoacetyl derivative in alcohol. In all cases dehydrodi-2-hydroxy-1-naphthylmethane was obtained in high yield.

Dehydrodi-2-hydroxy-3 : 5 : 6-trimethylphenylmethane (IV).—Alcohol was added to a mixture of the relevant hydroxy-compound (3 g.; Zincke and Hohorst, *Annalen*, **1907**, **353**, 363) and 2N-sodium hydroxide until the insoluble monosodium derivative of the phenol had dissolved. A slight excess of aqueous sodium hypochlorite (3%) was added to the stirred solution; the yellow mass which had separated was then removed and purified from aqueous acetone. The *product* (2·7 g.) formed small yellow prisms, m. p. 137° (Found: C, 80·6; H, 7·7; *M*, 272. $C_{19}H_{22}O_2$ requires C, 80·8; H, 7·8%; *M*, 282).

Dehydro-1-(2'-hydroxy-3' : 5'-dimethylbenzyl)-2-naphthol (VI).—A solution of the relevant hydroxy-derivative (this vol., p. 1351; 6 g.) in 2N-sodium hydroxide (20 c.c.) was added to stirred aqueous sodium hypochlorite (240 c.c.; 1%). The insoluble yellow product was washed with warm aqueous sodium hydroxide and the dry residue was treated with boiling light petroleum. The residue obtained after removal of the solvent was submitted to repeated fractionation by the same process; the required *product* separated in yellow prisms, m. p. 107°, when the solvent was allowed to evaporate spontaneously (Found: C, 82·3; H, 5·6. $C_{19}H_{16}O_2$ requires C, 82·6; H, 5·8%). The sparingly soluble *phenylhydrazone* was readily obtained from the crude product of the foregoing preparation by reaction with phenylhydrazine in hot acetic acid; it formed orange prisms, m. p. 167°, from aqueous acetone (Found: N, 7·6. $C_{25}H_{22}ON_2$ requires N, 7·6%).

Monosodium di-2-hydroxy-3 : 5 : 6-trimethylphenylmethane separated when a mixture of the hydroxy-compound (1 mol.) and 2N-sodium hydroxide (2 mols.) was warmed (90°). Exactly sufficient alcohol was added to effect solution; when the liquid cooled, the pure material separated in needles; these lost some water at 100° and finally melted at 175° (approx.). It was readily soluble in ether and in warm benzene, the latter solvent effecting partial dehydration. This covalent derivative was dried at 25° before analysis (Found: Na, 6·1. $C_{19}H_{23}O_2Na,4H_2O$ requires Na, 6·1%). Water was removed from it in a vacuum at 118° (P_2O_5) (Found: Na, 7·6. $C_{19}H_{23}O_2Na$ requires Na, 7·5%). Di-2-hydroxy-3 : 5-dimethylphenylmethane (V) (Fries and Kann, *Annalen*, 1907, **353**, 352) was completely soluble in N-alkali hydroxide; no covalent monosodium derivative could be obtained from it under the usual conditions or others. Addition of hypochlorite to the alkaline solution yielded an amorphous, unstable, green material; this was insoluble in the usual solvents and no simple dehydro-derivative could be isolated from it.

Monosodium 6-bromodi-2-hydroxy-1-naphthylmethane separated in the crystalline state when a solution of the hydroxy-compound (1 mol.) in warm N-sodium hydroxide (2 mols.) was cooled. After being dried (18°), it showed the usual solubility in ether, benzene or chloroform; it melted at 215° (approx.) after losing water at about 100° (Found: Na, 4·5. $C_{21}H_{14}O_2BrNa,6H_2O$ requires Na, 4·5%).

Monosodium Phenyldi-2-hydroxy-1-naphthylmethane.—When alcohol was added to a hot (90°) mixture of the hydroxy-compound (1 mol.) (Hewitt and Turner, *Ber.*, 1901, **34**, 302) and N-sodium hydroxide (2 mols.), the *sodium* derivative, which had separated, dissolved. This crystallised from the cooled solution in plates, which were dried in air (15°) (Found: Na, 4·9. $C_{27}H_{19}O_2Na,4H_2O$ requires Na, 4·9%). Part of the water was lost when the substance was dried at 35° (Found: Na, 5·5. $C_{27}H_{19}O_2Na,2H_2O$ requires Na, 5·3%). The tetrahydrate was readily soluble in ether and in warm benzene; the dihydrate was less soluble and separated when the benzene solution of the tetrahydrate was boiled.

King's College, London. [*Received, November 3rd, 1937.*]

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407. *The Lubrication of Taps with the Phosphoric Acids.*

By David L. Chapman and Lionel A. Moignard.

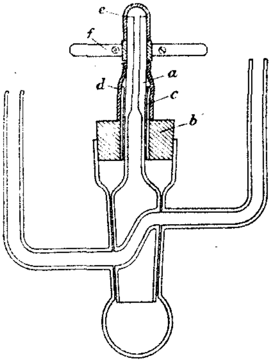
A new tap is described in which phosphoric acid is used as lubricant. Details are given for the preparation of the latter and for using the tap.

Hitherto the lubricant used for taps has been made from one or other of the phosphoric acids or from a mixture of the acids when it has been required to exclude from the

apparatus the vapours of organic compounds, as in spectroscopic investigations and in work with corrosive gases. However, the difficulties encountered when these inorganic lubricants are employed are considerable. If the lubricant is of such a composition that the tap will turn at room temperature, it is gradually pressed out from between the key and the barrel, and in a week or so the tap seizes or the mercury, which must be used to protect the lubricant from the moisture of the air, creeps down to the bore and enters the apparatus. Moreover, the pressure of the water vapour of such a lubricant is not inconsiderable, and commercial specimens of phosphoric acid and its anhydride are liable to contain volatile impurities which in several investigations have been shown to affect the results appreciably.

These difficulties have been overcome by the use of a specially prepared lubricant and a suitably designed tap. The latter can be used continuously with or without turning for months with very little danger of its ceasing to function satisfactorily.

The Lubricant.—The lubricant is prepared entirely from fused metaphosphoric acid, since the fused ortho-acid is liable to be contaminated with organic impurities. About 35 g. of metaphosphoric acid (sticks) are thoroughly rinsed several times with distilled water, transferred to a porcelain basin, and covered with water. The whole is heated at about 110° with occasional stirring until the acid is dissolved, and the clear solution obtained is maintained at the same temperature for 2 hours. The solution is thereby completely converted into an aqueous solution of orthophosphoric acid. The temperature of the oven is then kept at 140—150° for another 2 hours in order to concentrate the solution. The liquid is then transferred to a heavy-weight "Monax" boiling-tube, and heated with the flame of a Bunsen burner until the b. p. indicated by a thermometer immersed in the solution rises to 310°. After this the thermometer is removed, and the boiling continued for a definite time depending on the temperature at which the lubricant is required to soften. We find that with the quantities given, fairly vigorous boiling for a little under 2 minutes will provide a lubricant for a tap required to turn smoothly at 80°. The mouth of the tube is then closed with a rubber stopper through which a well-fitting glass rod has been previously inserted so that the rod reaches almost to the bottom of the tube.



The Taps.—These are of the usual mercury-sealed type, modified as shown in the diagram. The stem of the key, *a*, is a thick-walled glass tube, which is open to the cavity of the key. The key is not, as is usual, provided with a hole in its shoulder for the admission of mercury to the interior of the tap. The mercury can be introduced through the tubular stem of the key. The cup of the barrel of the tap is fitted with a rubber stopper, *b*, through which a short length of thin-walled glass tubing, *c*, is inserted so that the stem of the key when in position does not touch the inner surface of the tube. To prevent the entrance of air to the cup of the tap, a rubber tube, *d*, which fits but does not grip the stem of the key, is passed over the glass tube inserted through the stopper. Air is prevented from entering the cavity of the key by fitting on to the end a rubber cap, *e*. A metal handle, *f*, is clamped to the stem when the tap is being used. As shown in the diagram the key should extend beyond the barrel so as to protrude about 1 mm. into the mercury reservoir at the bottom of the latter.

Method of Lubricating the Taps.—The outside of the tap is heated by its being partially immersed in hot water, at the temperature at which the lubricant will become moderately mobile. The tube containing the lubricant is suspended in the same bath. When the lubricant is sufficiently soft, the key of the tap is removed and liberally smeared with lubricant, especially at the top and the bottom, the glass rod previously mentioned being used for the purpose. It is then inserted into the barrel, which has been removed from the bath, and pressed thoroughly home with much slow turning and repeated heating until there is close

optical contact between the barrel and the key. Excess lubricant will have been squeezed out at the top and bottom of the key and at the entrances to the bore. If the passages to the bore have thereby become stopped, they must be opened while the lubricant is still soft by drawing a current of air through the tap with the water pump. The tap is allowed to cool, and then hot distilled water is sucked through the tubes until all phosphoric acid has been removed from the bore and side tubes. After this operation the drying of the tubing can be easily accomplished. The surface of the lubricant pressed out at the top of the key is liable during manipulation to become moist, and this may determine crystallisation, which, however, can be prevented by pouring molten lubricant into the cup.

Use of the Tap.—The tap is sealed into place. Mercury is introduced through the hollow handle until it reaches a position just below the bore, and the cap is replaced at the top of the stem. The tap can be turned conveniently by surrounding it with water warmed to an appropriate temperature, and slowly rotating the key after the lubricant has become soft. During this operation the temperature of the tap should not be higher than that at which the key will turn smoothly although slowly without the application of force.

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408. *The Application of the Glass Electrode to the Measurement of the* p_H *of Slightly Buffered and Unbuffered Solutions.*

By EDWARD G. EDWARDS and DAVID P. EVANS.

The alkaline drift observed by previous investigators when using the glass electrode in unbuffered solutions has been avoided by agitating the liquid in contact with the membrane, whereby the very small amount of alkali dissolved from the glass is quickly dispersed throughout the test liquid and causes no measurable change in p_H. The soft-glass electrodes usually employed for electrometric purposes yield accurate results for the p_H of acid solutions, conductivity water of p_H about 7·0, very pure water, and solutions of neutral salts. The p_H values thus determined agree very well with those given by the isohydric indicator method. Since, in solutions of p_H less than 7·0, the glass electrode acquires its equilibrium potential within 1 minute, the apparatus is suitable for the measurement of the p_H of slightly buffered acidic solutions in which the hydrogen-ion concentration is slowly changing.

BEFORE the commencement of the present work (early in 1935), the only satisfactory measurements of p_H in unbuffered solutions were those of Kolthoff and Kameda (*J. Amer. Chem. Soc.*, 1931, **53**, 821, 825), who employed the hydrogen electrode and the isohydric indicator method. Burton, Matheson, and Acree (*Ind. Eng. Chem. Anal.*, 1934, **6**, 79) had stated that the glass electrode gave results in good agreement with those obtained by the colorimetric method, but Laug (*J. Amer. Chem. Soc.*, 1934, **56**, 1034) reported drifts in potential indicating a slow development of alkalinity; these drifts were attributed to solution of alkali from the glass membrane (compare Schwabe, *Z. Elektrochem.*, 1935, **41**, 681; also Ellis and Kiehl, *J. Amer. Chem. Soc.*, 1935, **57**, 2139). We have confirmed these observations, and the method described below was based upon the view that such drifts might be avoided by use of a relatively large volume of the test liquid and continuous agitation by a stream of purified air; the dissolved alkali should then be quickly dispersed throughout the liquid with a negligible effect upon the p_H value.* These expectations have been amply confirmed by the consistent and reproducible character of the results and their agreement with those of the isohydric indicator method. In other recent investigations (Ellis and Kiehl, *loc. cit.*; Schwabe, *Z. Elektrochem.*, 1936, **42**, 147) the drift has been eliminated by allowing the test liquid to flow over the glass membrane: our method is simpler and requires less liquid.

* Recent publications (up to October 1937) make no reference to the use of a non-reactive gas for this purpose, but since the preparation of this paper Cranston and Brown (*Trans. Faraday Soc.*, 1937, **33**, 1455) have described a method in which the alkaline drift is avoided by passage of purified air.

The liquids to which our procedure has been applied include (1) distilled water, (2) conductivity water freed from carbon dioxide, (3) very dilute alkali, (4) very dilute acid, (5) specially pure water, (6) dilute solutions of hydrochloric acid, potassium chloride, ammonium chloride, and lead nitrate. The results are summarised below. In cases 1—5 good agreement with the isohydric indicator method is obtained. The value recorded for 0·01M-potassium chloride confirms that given by Kolthoff and Kameda (*loc. cit.*).

Liquid.	Temp.	Electrometric p_H.	Colorimetric p_H.
1 Distilled water	30°	5·12	5·10
2. Conductivity water	30	7·14	7·25
3. Very dilute alkali	30	8·18	8·17
4. ,, acid	30	6·50	6·56
5. Specially pure water	20	7·15	7·15
6. 0·957 × 10^{-5}M-HCl	30	5·02	5·02 *
7. 0·01011M-KCl	20—23	6·75	—
8. 0·01M-NH_4Cl	18—19	5·62	—
9. 0·00996M-$Pb(NO_3)_2$	20—20·5	5·34	—

* Theoretical p_H on the assumption of complete ionisation.

Experimental.

Materials.—Specially pure water was obtained by using a block-tin condenser essentially like that of Ellis and Kiehl (*loc. cit.*, p. 2145). In preliminary experiments, distilled water containing from 0·025 to 0·0001M-phosphoric acid was redistilled in the still, but in each case the distillate had a p_H of 6·5—6·7 when freed from carbon dioxide. This acidity, due to the presence of traces of volatile acid in the laboratory distilled water, was removed by distillation from alkaline permanganate before distilling from M/5000-phosphoric acid in the special still. The phosphoric acid was of 'AnalaR' quality, previously heated to fuming point for 30 minutes. The water thus obtained was consistently within the p_H limits 6·9—7·15 when freed from carbon dioxide.

Hydrochloric acid solutions were made in Pyrex flasks from conductivity water and constant-boiling acid. Water of p_H *ca.* 6·5 was obtained by redistilling distilled water from dilute phosphoric acid in the special still; and a rapidly conducted distillation in a Vogel still yielded an alkaline water of p_H *ca.* 8·0. 'AnalaR' Specimens of potassium and ammonium chlorides were thrice recrystallised from pure water, the former salt being fused in a platinum crucible before use. Lead nitrate was purified by the method of Cranston and Brown (*J. Roy. Tech. Coll.*, 1937, **4**, 54). All salt solutions were made in very pure water.

The air used in the preparation of pure water and in the electrometric and the colorimetric determinations of p_H was purified by passing through three 15-inch tubes filled with soda-lime, a wash-bottle containing concentrated sodium hydroxide solution, two wash-bottles filled with dilute phosphoric acid, and lastly through two bubblers containing conductivity or very pure water. In the air-purification train attached to the glass-electrode vessel (*via* the ground glass joint at *J*) the last four bubblers containing the phosphoric acid and water were made of Pyrex-glass-stoppered tubes filled with glass beads and were connected to each other by glass seals. This precaution eliminated the possibility of ammonia exhaling from the rubber connections and entering the test liquid in the cell. Any spray was prevented from passing along with the pure air by plugs of cotton-wool in the top of the last bubbler tube.

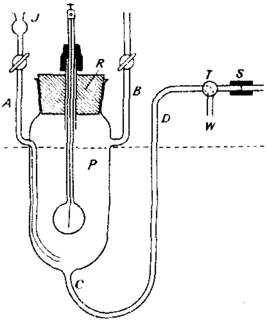
The buffer solutions employed were those of Clark and Lubs (*J. Bact.*, 1917, **2**, 1, 109, 191), and were checked electrometrically at 30° before use with either the quinhydrone electrode or the hydrogen electrode as designed by Lockwood (*J. Soc. Chem. Ind.*, 1935, **54**, 295T). The glass electrodes were of the Haber bulb type with a stem of length 20 cm. These were filled with either an acid buffer saturated with quinhydrone or a 1% solution of chloroplatinic acid 0·01M. with respect to hydrochloric acid (compare Parsy, *J. Soc. Leather Trades Chem.*, 1936, **20**, 188). A long platinum wire, soldered to a gold-plated terminal and covered with Pyrex capillary tubing except for a length of 2 cm. at the lower end, was used for electrical contact with the solution in the electrode bulb. Calibration of the electrode over the p_H range 1—9·5 at 30° was carried out in the apparatus described below. Electrodes made from the special soft glass supplied by Messrs. Dixon and Co., London, attained equilibrium in about 1 minute and exhibited a linear relation between *E.M.F.* and p_H. Electrodes made from ordinary laboratory soda glass, however, showed a linear relation only below p_H 7·0. Above this value the potentials in buffer solutions were lower than theoretical.

In measuring the p_H of a test solution, the electrodes were standardised by determinin the *E.M.F.* of the cell filled with a buffer solution of approximately the same p_H as th unknown. The latter was then calculated from the equation $E_X - E_B = 0{\cdot}0601(p_{HX} - p_{HB})$ in which E_X denotes the *E.M.F.* of the cell.

$$\text{Pt}|\text{acid buffer satd. with quinhydrone}|\text{glass}|\text{soln. } p_{HX}|\text{KCl satd., } Hg_2Cl_2 \text{ satd.}|\text{Hg}$$

containing the unknown solution of p_{HX}, and E_B represents that of the cell when filled wit the buffer solution of p_{HB}.

The glass-electrode cell is shown in the figure, which is self-explanatory. The vessel *P* wa of about 200 ml. capacity, and all parts were made of Pyrex glass. Purified air was passe through the test liquid in *P via* the side tube *A* The air exit tube *B* was fitted with an all-glas Volhard trap filled with water. Electrical connexio between the test liquid and the saturated potassiu chloride of the saturated calomel electrode attache at *S* was made *via* the tube *CD* and the three-wa tap *T* as described by Morton (*J. Sci. Instr.*, 1930 7, 187). The rubber stopper, *R*, was treated wit castor oil at 80° in a vacuum to prevent leakage o ammonia from the rubber. The whole apparatu was immersed to the level of the broken line in copper bath filled with heavy paraffin oil maintaine at 30°. The bath was earthed, and this forme sufficient electrical shielding.



About 100 ml. of test liquid were introduced int the vessel *P*, and the electrode placed in position. Th liquid junction was formed by suitably turning tap *T* and drawing a little of the test liquid out through the exit *W*. Next, the tap *T* was turned, and a small volume of saturated potassium chloride solution was withdrawn from the calomel electrode through the same exit. One complete turn of the tap then caused the formation of a thin layer of saturated potassium chloride around the barrel of the tap. This layer provided sufficient electrical connexion, and on closing *T*, the possibility of diffusion of potassium chloride i minimised. When necessary a current of purified air was passed through the test liquid in the manner described. The *E.M.F.* of the cell was read on a valve electrometer p_H meter graduated in mv. or 0·02 p_H, as supplied by the Cambridge Instrument Co.

All colorimetric measurements on unbuffered solutions were carried out by the method of Kolthoff and Kameda (*loc. cit.*).

Results.—Hydrochloric acid. For $0{\cdot}957 \times 10^{-5}$—$0{\cdot}957 \times 10^{-1}$M-solutions, several soft-glass electrodes yielded theoretical results for the p_H, indicating that the junction potential is the same for solutions of moderate and of very small ionic strength. Passage of air through the solutions for several hours did not cause a change in p_H.

Distilled water. The p_H was obtained without aeration. Four soft-glass electrodes gave p_H 5·11±0·01, the colorimetric value being 5·10.

Conductivity water. Water having $\kappa = 1{\cdot}0$ gemmho was boiled for 1 minute and quickly poured into the cell; the electrode was introduced and aeration commenced. After 30 minutes, the liquid junction was formed, and *E.M.F.* readings were taken at intervals. The p_H of the water increased slowly but reached a constant value of about 7·1 after one hour. This value was maintained on continued aeration for long periods (24 hours). A typical set of readings was:

Time (mins.)	3	11	21	27	36	78	18 (hrs.)
p_H	6·94	7·06	7·09	7·10	7·11	7·09	7·12

(Colorimetric p_H 7·20.)

Constancy of the liquid junction was checked by repeated reflushing of both test liquid and saturated potassium chloride through the three-way tap *T* as previously described. If aeration was stopped, a rise in p_H took place, the extent and rate of which varied with each soft-glass electrode. Resumption of the air flow caused the p_H to fall immediately to its

former value. For example, after 18 hrs.' aeration the above solution (p_H 7·12) behaved as follows :

Time (mins.)	{aeration stopped}	2	4	8	15	{aeration restarted}	16	30
p_H		7·15	7·17	7·20	7·25		7·13	7·12

The rise in p_H is undoubtedly due to dissolution of the soft glass in the water. Although the rate of solution is small, however, the rate of diffusion is smaller, as is indicated by the observation that for all soft-glass electrodes the p_H reached a maximum value of about 0·2—0·5 unit above the previous value on stopping the aeration. This value was then maintained over a considerable period, with a tendency to reach even higher values very slowly. Agitation of the test liquid by the air stream dispersed this alkalinity throughout the bulk of the liquid, causing a fall in p_H to the former value. These results show that agitation of the liquid in contact with the glass electrode precludes the formation of a thin alkaline layer around the membrane and prevents the occurrence of the drift towards the alkaline region as observed by Laug, by Ellis and Kiehl, and by Schwabe (*loc. cit.*). Experiments of the type described above were carried out with glass electrodes made from ordinary laboratory glass, but in general the behaviour of these electrodes in unbuffered solutions was not so consistent and reproducible as that of the special soft type. On the other hand, no alkaline drift was observed on stopping the aeration. The occasional anomalous results given by the laboratory-glass electrodes (due probably to sudden changes in asymmetry potentials) made them less suitable than the special soft electrodes for measurements on unbuffered solutions of p_H about 7.

Slightly acid water. The p_H of such water (p_H *ca.* 6·5) was readily measured, aeration for 2 hours being sufficient to give a constant p_H which agreed with the colorimetric value to within 0·1 unit.

Slightly alkaline water. Aeration for about 200 minutes gave fairly constant p_H values, but the laboratory-glass electrodes (denoted by H) always yielded p_H's higher than those given by the soft-glass electrodes (denoted by S) by about 0·25—0·30 unit. For example :

Electrode	S. 1.			S. 9.		H. 5.		
Experiment :	A.	B.	C.	A.	B.	A.	B.	(Colorimetric).
p_H	8·15	8·18	8·10	8·10	8·04	8·35	8·35	8·17

This discrepancy is probably to be traced to the anomalous behaviour of the H electrodes in buffer solutions. McInnes and Dole (*J. Amer. Chem. Soc.*, 1930, **52**, 29) have shown that the deviations of the potentials of glass electrodes from the theoretical values in alkaline solutions are dependent upon the concentration of alkali-metal ions in solution. This deviation should therefore be greater in the buffer solutions in which [Na^+] is approximately 0·05M. than in the slightly alkaline water of the same p_H in which [Na^+] is of the order 10^{-4}M. It appears, therefore, that the apparently high values of the p_H of unbuffered solutions of p_H *ca.* 8, as measured by the laboratory-glass electrodes, are due, not so much to the incorrect behaviour of the electrodes in these solutions, as to the departure from theoretical behaviour in the buffer solutions used for calibration.

Very pure water. For the determination of the p_H of such water the cell assembly was modified in order to lower its electrical resistance. The connecting arm *CD* was shortened, and fused in near the bottom of the electrode vessel *P*. The arm was bent vertically downwards before making connexion *via* the three-way tap with the arm of the saturated calomel electrode. This apparatus was suspended in air from a suitably insulated stand. About 100 ml. of pure water were poured quickly into the cell, and the glass electrode inserted. Aeration was commenced, and *E.M.F.* readings taken at intervals, a constant p_H being recorded after 3 hours. Several measurements conducted on different samples of pure water gave results within the p_H range 6·9—7·15 at 20°.

Dilute salt solutions. The modified apparatus was also used in these cases. The p_H–time curves for potassium chloride solutions were similar in shape to, but situated slightly below, those for pure water. After 4—5 hours' aeration the observed p_H was constant at a value reproducible to within 0·02 unit for any given solution of potassium chloride. Results after 5 hours' aeration at 20—23·4° are recorded below :

KCl, M. × 10^6	1011	112	13·2	1·3	(water)
p_H	6·75	6·86	6·90	6·93	6·98

These results are in agreement with those of Kolthoff and Kameda rather than with those of Ellis and Kiehl.

The measurement of the p_H of solutions of ammonium chloride was simply carried out because the effect of carbon dioxide is relatively unimportant. The p_H attained after a few minutes' aeration was constant and remained so for long periods. The mean values obtained at 18—19° by using several S-type electrodes are given below; each electrode agreed to within 0·01 unit of p_H.

NH_4Cl, M.	0·25	0·05	0·01
p_H	5·05	5·41	5·62

The p_H values of solutions of lead nitrate have been measured by Denham and Marris (*Trans. Faraday Soc.*, 1928, **24**, 515), using a quinhydrone electrode, and very recently by Cranston and Brown (*loc. cit.*), using a glass electrode. In the present measurements, constant *E.M.F.*'s were attained in a few minutes and did not alter on long-continued aeration of the solution. All soft-glass electrodes agreed to 0·01 unit of p_H, and the table below gives the mean results.

Lead nitrate solutions. Temperature 20—20·5°.

$Pb(NO_3)_2$, M.	p_H.	$K_H \times 10^8$.	$Pb(NO_3)_2$, M.*	p_H.*
0·1001	4·28	2·76	0·1	4·17
0·0101	4·89	1·66	0·01	4·92
0·00402	5·11	1·77	0·004	5·11
0·00208	5·22	1·77	0·002	5·24
0·00996	5·34	2·10	0·001	5·34

* Results recorded by Cranston and Brown (*loc. cit.*).

The p_H values are in good agreement with those of Cranston and Brown, except for the 0·1M-solution. In this solution, however, a precipitate of lead chloride formed at the liquid junction, no reference to which is made by those authors. In spite of this precipitation, the p_H value of this solution was reproducible in our measurements to 0·02 unit. Further, the hydrolysis constant (K_H) for this solution is in slightly better agreement with that for the lower concentrations than is Cranston and Brown's ($4·60 \times 10^{-8}$).

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TECHNICAL COLLEGE, CARDIFF. [*Received, October 15th, 1937.*]

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409. *An Electrometric Study of Dilute Aqueous Solutions of Halogenated Ketones.*

By E. G. EDWARDS, D. P. EVANS, and H. B. WATSON.

An examination of dilute aqueous solutions of several halogenated acetones, using the glass electrode and a silver–silver halide electrode, has given results which indicate that the acidity of these solutions, first observed by Watson and Yates in 1932, is due to hydrolysis of the ketone. Either the replacement of halogen by hydroxyl or the production of haloform may predominate, or both may occur simultaneously. The structural conditions which facilitate haloform formation are discussed.

Two suggestions have been advanced to interpret the acidic reaction observed by Watson and Yates (J., 1932, 1214) in dilute aqueous solutions of halogenated acetones, ionisation of hydrogen resulting from (*a*) the change $>CH{\cdot}CO \longrightarrow >\overset{\ominus}{C}{\cdot}CO + \overset{\oplus}{H}$ (*loc. cit.*, p. 1209), or (*b*) the co-ordination of hydroxyl ion at carbonyl carbon (Watson, Nathan, and Laurie, *J. Chem. Physics*, 1935, **3**, 170): $>CH{\cdot}C{=}O + H_2O \longrightarrow >CH{\cdot}C{<}^{O^{\ominus}}_{OH} + H^{\oplus}$. Further investigation, however, has revealed the presence of halide ions in the solutions, and of chloroform in aqueous solutions of hexachloroacetone. These discoveries suggested that the observed acidity was to be ascribed, not to the ionisation of the ketones, but to hydrolysis, either of the "alkyl halide type" (1) or of the "haloform type" (2):

$$R{\cdot}CO{\cdot}CH_2X + H{\cdot}OH \rightleftarrows R{\cdot}CO{\cdot}CH_2{\cdot}OH + HX \quad . \quad . \quad . \quad (1)$$

$$R{\cdot}CO{\cdot}CX_3 + H{\cdot}OH \longrightarrow R{\cdot}CO_2H + CHX_3 \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Reaction (1) is reversible as shown by the decrease in concentration of halide ion when sulphuric or nitric acid is added. When water is in excess, the velocity of change is therefore represented by the equation $dx/dt = k_1(a - x) - k_2x^2$, but in the cases examined the extent of the hydrolysis was so small that the results were not suited to mathematical treatment. The reaction is characterised, however, by the equality of the concentrations of hydrogen and halide ions.

No halogen acid is produced in reaction (2), but even if this reaction occurs alone in solutions of ketones such as pentachloro-, hexachloro-, or *as*-tetrabromo-acetones, halide ions are likely to appear owing to the further hydrolysis of the halogenated acetic acid. The haloform cleavage takes place readily in presence of bases (*e.g.*, OH′, OAc′); ωωω-trichloroacetophenone, for example, may be heated with water for 7 hours at 170° without any apparent change, but chloroform is liberated immediately on addition of a drop of potassium hydroxide (Houben and Fischer, *Ber.*, 1931, **64**, 2636). The velocity of reaction (2) may therefore be written $dx/dt = k[\text{ketone}][OH'] = k'[\text{ketone}]/[H^{\cdot}] = k'(a - x)/x$ (complete ionisation of the halogenated acetic acid being assumed in the dilute solutions employed), which gives on integration

$$kt = a \log[a/(a - x)] - x \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

For $x = a/2$, t is proportional to a, *i.e.*, the half-period ($t_{1/2}$) varies directly as the initial concentration of ketone.

In our experimental investigation, dilute solutions of the halogenated ketones were prepared in pure water, free from carbon dioxide. The velocity at which hydrogen ions appeared in the solution (at 30°) was then determined by use of the glass electrode (preceding paper), and the development of halide ions was followed by means of a silver–silver halide electrode (see experimental section). The results may be summarised as follows:

(*a*) In M/500-aqueous solutions of *s*-dichloroacetone the concentration of chloride ion is throughout equal to that of hydrogen ion, within the limits of experimental error; the same applies to ω-chloroacetophenone.

(*b*) The concentration of chloride ion in M/200- to M/2000-aqueous solutions of hexachloroacetone is only about 2% of that of hydrogen ion, and the latter finally becomes approximately equal to the initial concentration of the ketone. Moreover, the experimental figures for hexachloroacetone give fairly good constants when substituted in equation (3), and $t_{1/2}$ is very nearly proportional to the initial concentration (in g.-mols./l.) of ketone (see below).

Development of acidity in hexachloroacetone solutions at 30°.

[ketone]	0·005	0·002	0·001
10^4k	0·141	0·136	0·137
$t_{1/2}$ (mins.)	70·0	27·5	14·5
$10^{-3}t_{1/2}$/[ketone]	14·0	13·8	14·5

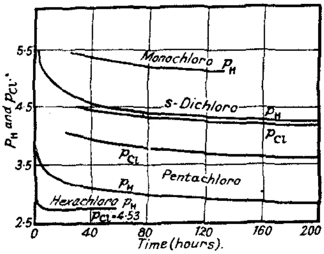
(*c*) Pentachloro- and *as*-tetrabromo-acetones (both containing the grouping $-CX_3$) occupy an intermediate position. The concentration of halide ions, although considerable, is much less than that of hydrogen ion.

These results are represented diagrammatically in Figs. 1 and 2. They lead to the conclusions that the acidity of solutions of the lower halogenated acetones (*e.g.*, *s*-dichloro-) is to be ascribed to hydrolysis of the "alkyl halide type," while that of hexachloroacetone solutions is due almost entirely to the haloform cleavage, and that both reactions proceed simultaneously in the case of pentachloro- and *as*-tetrabromo-acetones.

The occurrence of the haloform cleavage in trihalogenated ketones and aldehydes of the type $R{\cdot}CO{\cdot}CX_3$ is clearly to be correlated with other special properties of these compounds, such as the stability of their hydrates and other addition products (*e.g.*, the addition compound of chloral and hydroxylamine isolated by Hantzsch, *Ber.*, 1892, **25**,

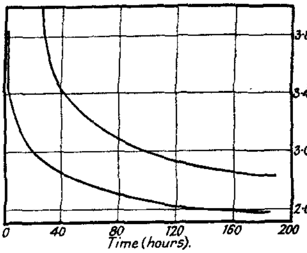
702) and their susceptibility to base-catalysed prototropic change (Watson and Yates, *loc. cit.*, p. 1212). All these phenomena have their origin in the electron-attractive

FIG. 1.



Development of p_H *and* p_{Cl} *in* M/500-*chloroacetones.*

FIG. 2.



Development of p_H *and* p_{Br} *in* M/500-as-*tetrabromoacetone.*

character of the halogen substituents, which promote the combination of carbonyl carbon with nucleophilic reagents (compare also the effect of electron-attractive groups upon the alkaline hydrolysis of esters and the base-catalysed prototropy of acetophenones). The halogen atoms of $R{\cdot}CO{\cdot}CX_3$ therefore render the carbonyl group very reactive towards hydroxyl and other bases (*e.g.*, acetate ion, alkoxyl ion). There is, however, an additional factor which contributes to the facility with which the haloform cleavage can occur. This change may be compared with the alkaline hydrolysis of esters, as indicated in the following schemes :

$$\text{Ester hydrolysis,}\quad R{\cdot}C{\overset{\displaystyle /\!\!/ O}{\underset{\displaystyle \backslash OR'}{}}} \xrightarrow{OH'} R{\cdot}C{\overset{\displaystyle / O^{\ominus}}{\underset{\displaystyle \backslash OR'}{\leftarrow O\vdots H}}} \longrightarrow R{\cdot}CO{\cdot}O' + HOR'$$

$$\text{Haloform cleavage,}\quad R{\cdot}C{\overset{\displaystyle /\!\!/ O}{\underset{\displaystyle \backslash CX_3}{}}} \xrightarrow{OH'} R{\cdot}C{\overset{\displaystyle / O^{\ominus}}{\underset{\displaystyle \backslash CX_3}{\leftarrow O\vdots H}}} \longrightarrow R{\cdot}CO{\cdot}O' + CHX_3$$

In the former case the alkoxyl group OR′ is eliminated (Polanyi and Szabo, *Trans. Faraday Soc.*, 1934, **30**, 508), and CX_3, when linked to carbonyl (a necessary condition for the occurrence of the haloform cleavage; see summary by Fuson and Bull, *Chem. Reviews*, 1934, **15**, 275), behaves similarly. Like alkoxyl, it can form a stable compound by the addition of a single proton, and the electron-attraction of the three halogen atoms enables it to break away with the electron pair by which it was linked to carbonyl carbon. The comparison may be extended to include $-CX_3$, –OR (in esters), $-NR_2$ (in acid amides), and –X (in acyl halides).

Our results are therefore in accordance with expectation. Whereas *s*-dichloroacetone is attacked by a nucleophilic reagent at the α-carbon atom, Cl being replaced by OH (reaction 1), the haloform cleavage (reaction 2), which involves the attack of the reagent upon carbonyl carbon, becomes prominent in ketones which have three halogens linked to the same α-carbon atom, and in hexachloroacetone the carbonyl group is so activated that this change occurs to the almost complete exclusion of reaction 1.

EXPERIMENTAL.

Halogenated Ketones.—Monochloroacetone was purified by three distillations at atmospheric pressure, followed by one at low pressure; b. p. 119°/763 mm. *s*-Dichloroacetone (m. p. 42·5°) and *as*-tetrabromoacetone (m. p. 36·3°; Found : Br, 87·5. Calc. for $C_3H_2Br_4O$: Br, 87·6%) were recrystallised to constant m. p. from light petroleum. Penta- and hexa-chloroacetones were prepared by prolonged chlorination of acetone. Chlorine was passed into acetone

dissolved in 90% acetic acid in presence of a little hydrochloric acid for 12 hours at room temperature, and then, after addition of sodium acetate (since bases catalyse the halogenation of the higher halogenated acetones more powerfully than do acids), for a further 40 hours in boiling solution. The resulting liquid was poured into twice its volume of water, and the oil removed. The aqueous solution was extracted three times with chloroform, and extract and oil dried over anhydrous sodium sulphate. After repeated fractionation under low pressure in a Claisen flask fitted with a 12-pear column, hexachloroacetone was obtained by freezing out the fraction of b. p. > 103°/40 mm.; it was purified by freezing, and finally by distillation under low pressure. It was a colourless liquid, b. p. 110°/40 mm., m. p. – 3° to – 4° (Found : Cl, 80·4. Calc. for C_3Cl_6O : Cl, 80·36%). Continued fractionation of the liquid of b. p. < 103°/40 mm. led to a fraction of b. p. 97·5—99·5°/40 mm., and on cooling below 0° pentachloroacetone separated as a solid. It was purified by freezing and finally by distillation under low pressure; b. p. 97·5—98·5°/40 mm., m. p. 2·1° (Found : Cl, 77·0. Calc. for C_3HCl_5O : Cl, 77·0%). ω-Chloroacetophenone, obtained by chlorination of acetophenone in glacial acetic acid, was recrystallised from alcohol; m. p. 54·5°.

Detection of the Haloform Reaction in Aqueous Solutions of Hexachloroacetone.—Small quantities of chloroform are removed completely from aqueous solution by passage of air for an hour at 30°. The chloroform can be collected in a glass spiral immersed in solid carbon dioxide–ether. This method was used in the detection of chloroform in aqueous solutions of hexachloroacetone. 2 L. of a M/200-solution stood at 30° for 2 hours. Purified air was passed through half of this solution and then through the cooled spiral for 2 hours. At the end of this period the p_H values of the two portions of the solution were identical (2·48). Chloroform was detected in the spiral (odour and b. p.). Similar aeration of 1 l. of a solution M/200 with respect to both trichloroacetic acid and chloroform gave a similar quantity of chloroform. It appears justifiable to suppose that the hexachloroacetone had been completely, or almost completely, converted into trichloroacetic acid and chloroform, and this is in harmony with the results of the electrometric measurements.

Electrometric Measurements.—During the initial stages of the reaction between halogenated ketones and water, the development of hydrogen-ion concentration was rapid, but became slow after 1—2 hours. A constant p_H was then approached after an interval of 3—10 days according to the ketone studied. The rapid change in p_H was followed in the glass electrode assembly (figure, previous paper) immersed in an oil-bath at 30°. A measured volume of pure water, previously boiled to remove carbon dioxide, was placed in the electrode vessel *P*, the rubber stopper carrying an S. glass electrode and a small stoppered glass tube was placed tightly in the mouth of the vessel, and a current of purified air passed through the liquid to remove traces of carbon dioxide. Previous tests had shown that this procedure yielded water of p_H 6·9—7·2, and addition of 1—2 ml. of absolute alcohol did not affect the measured p_H. A solution of ketone in absolute alcohol was made in a 5-ml. stoppered flask, and 1 ml. of this solution was added quickly from a small pipette through the stoppered glass tube in the rubber bung to the water of p_H about 7. Aeration was continued throughout the experiment. This procedure ensured the rapid solution of the ketone in water. One minute was allowed for thorough mixing of the solution by the air current, and the liquid junction between the saturated calomel and the test solution was made in the tap *T* (figure, previous paper). *E.M.F.* Readings were then taken at short intervals, zero time being the instant of half delivery of the ketone solution into the water. The constancy of the liquid-junction potential was shown as follows: (*a*) on quickly reflushing the liquids through the tap *T*, during the later (slow) changes in p_H no alteration was caused in the *E.M.F.* of the cell, and (*b*) experiments with solutions of the same concentration of a given ketone were reproducible to within 0·01 p_H unit as indicated in the following table, in which E_g represents the *E.M.F.* of the cell (1):

$$Pt|H_2PtCl_6|Glass|Soln.\ X|KCl\ satd.,\ Hg_2Cl_2\ satd.|Hg.$$

Initial Development of p_H *in* M/200-*Hexachloroacetone.*

Time (mins.).	E_g (mv.). A.	E_g (mv.). B.	Mean p_H.	Time (mins.).	E_g (mv.). A.	E_g (mv.). B.	Mean p_H.	Time (mins.).	E_g (mv.). A.	E_g (mv.). B.	Mean p_H.
3	238	238	3·23	8	252	252·3	2·99	16	260	260	2·85
4	243	243·5	3·14	9	253·8	253·5	2·97	18	261	261	2·84
5	247	246·5	3·09	10	254·8	254·8	2·95	20	262	262	2·83
6	249	249	3·05	12	256·6	256·9	2·91	26	265	265·5	2·78
7	251	250·9	3·03	14	258·6	259	2·87	30	266·4	266·6	2·75

The glass electrodes, which were calibrated in buffer solutions, exhibited a linear relatio between p_H and *E.M.F.* over the range p_H 1—9, and were checked after each series o measurements by using an acid buffer of known p_H as solution X in cell (1). The latte *E.M.F.*'s served for the calculation of the p_H of the ketone solutions by use of the formul $E_X - E_B = 0{\cdot}0601(p_{HX} - p_{HB})$ (compare preceding paper, p. 1940).

The measurements on solutions in which the p_H was changing slowly (see below) indicatec that with the exception of hexachloroacetone the p_{Cl} or p_{Br} developed by hydrolysis (equatior 1) during the first 2 hours was smaller than could be detected with a silver chloride or silver bromide electrode. The halide ion attained its equilibrium concentration in 3 minutes wher hexachloroacetone was dissolved in water. In order to ascertain whether the pure ketones contained free halide ion, 0·1M-sulphuric acid (halide free) was placed in the electrode vessel *P*, and a silver chloride electrode immersed in the solution. The *E.M.F.* of the saturated calomel–silver chloride cell was then measured. On adding 1 ml. of the alcoholic solution of the ketone, containing sufficient of the latter to make the acid M/500 with respect to ketone, no change was observed in the *E.M.F.*, a fall in which would have indicated presence of halide ions, since the sulphuric acid prevented hydrolysis of the "alkyl halide type."

In the slower stages of the reaction between water and halogenated ketones the changes in p_H and p_{Cl} were studied. Pyrex 250-ml. graduated flasks were steamed out and filled tc within 1 ml. of the mark at 30° with carbon dioxide-free pure water. 1 Ml. of the alcoholic solution of ketone was added quickly, the flask securely stoppered, and the solution well shaken and stored in a thermostat at 30°. At known times, samples of the solution were poured into the glass-electrode vessel and the p_H and p_{Cl} determined by means of a glass and a silver chloride electrode respectively. The glass electrodes were checked after each measurement, a buffer solution of approximately the same p_H as the ketone solution being used. The silver halide electrodes were prepared according to Keston (*J. Amer. Chem. Soc.*, 1935, **57**, 1671) and Rule and LaMer (*ibid.*, 1936, **58**, 2339) and were protected from daylight. The silver chloride electrodes were calibrated in the cell (2)

$$Ag|AgCl|HCl\ (c)|KCl\ \text{satd.},\ Hg_2Cl_2\ \text{satd.}|Hg$$

various concentrations of hydrochloric acid from 0·1M to 0·00001M being used. Between the limits p_{Cl} 1—4 a straight line was obtained on plotting the *E.M.F.*'s of cell (2) against the p_{Cl} calculated from the equation $p_{Cl} = -\log_{10}\alpha_{Cl}$, Lewis and Randall's activity coefficients of chloride ion ("Thermodynamics," p. 382) being used together with the concentrations of hydrochloric acid. At $p_{Cl}>4$ the *E.M.F.* of the cell is less than theoretical, and at p_{Cl} 5 it is almost independent of the p_{Cl} owing to the solubility effect of the silver chloride. This indicates the limiting concentration of chloride ion which can be measured directly with the silver chloride electrode. Different electrodes gave results agreeing to within 1 mv. at $p_{Cl}<4$, but as p_{Cl} 5 was approached the experimental error increased. The silver bromide electrodes were calibrated in dilute solutions of potassium bromide and exhibited theoretical behaviour up to p_{Br} 5. Above this the solubility effect of the silver bromide became evident. The p_{Cl} values of the ketone solutions were obtained from the calibration curve after determination of the *E.M.F.* of the cell (2) with the ketone solution replacing the hydrochloric acid. The following tables indicate the type of results obtained for the slower stages of the reactions.

M/500-Hexachloroacetone.

Time (hrs.).	p_H.	p_{Cl}.
28	2·76	4·53 (approx.)
56	2·75	4·60 ,,

M/500-ω-Chloroacetophenone.

Time (hrs.).	p_H.	p_{Cl}.
48	4·58	—
150	4·30	4·30

M/500-Pentachloroacetone.

Time (hrs.).	p_H.	p_{Cl}.
7·75	3·41	4·30
30	3·14	3·99
79	2·97	3·85
103	2·94	3·76
126	2·91	3·70
150	2·86	3·66
247	2·84	3·56

The remaining results are given in the graphs in Figs. 1 and 2.

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410. *Acid–Base Catalysis in the Depolymerisation of Dimeric Dihydroxyacetone.*

By R. P. Bell and E. C. Baughan.

The depolymerisation of dimeric dihydroxyacetone in aqueous solution has been studied kinetically by a dilatometric method. The reaction is of the first order, and is catalysed by both acids and bases in general. By using suitable buffer solutions catalytic constants were evaluated for H_2O, H_3O^+, OH^-, four carboxylic acids, and seven carboxylate ions. For both acid and basic catalysis there is a relation between the catalytic constants and the acid or basic strength of the catalysts. It cannot be decided whether the catalysis by water molecules represents acid or basic catalysis, or both.

It has long been known that a number of α-hydroxy-aldehydes and -ketones have twice the expected molecular weight in freshly prepared solutions, but change slowly to the unimolecular form on keeping. This behaviour has been observed with glycollaldehyde (Fenton and Jackson, J., 1899, **75**, 575), glyceraldehyde (Wohl, *Ber.*, 1898, **31**, 2394), and dihydroxyacetone (Bertrand, *Compt. rend.*, 1899, **129**, 341), and experiments in this laboratory with phenylglyceraldehyde, prepared by Fischer's method (*Ber.*, 1898, **31**, 1995), have shown that this substance behaves in the same manner. Little work has been done on the kinetics of the depolymerisation, though Bertrand's data (*loc. cit.*) suggest that the reaction is of the first order for dihydroxyacetone in water, and the same conclusion was reached by McCleland (J., 1911, **99**, 1827) for glycollaldehyde in a number of solvents.

The existence of dimeric forms is almost certainly due to semi-acetal formation between the two molecules, *e.g.*, for dihydroxyacetone :

$$2\ \mathrm{O{:}C}\!<\!\begin{matrix}\mathrm{CH_2\cdot OH}\\ \mathrm{CH_2\cdot OH}\end{matrix} \rightleftarrows \begin{matrix}\mathrm{HO}\\ \mathrm{OH\cdot CH_2}\end{matrix}\!>\!\mathrm{C}\!<\!\begin{matrix}\mathrm{CH_2\cdot O}\\ \mathrm{O\cdot CH_2}\end{matrix}\!>\!\mathrm{C}\!<\!\begin{matrix}\mathrm{OH}\\ \mathrm{CH_2\cdot OH}\end{matrix} \quad . \quad . \quad . \quad (1)$$

In the pentoses and hexoses an exactly similar linking between carbonyl and hydroxyl groups in the *same* molecule leads to the formation of a pyranose ring. The rupture of these pyranose rings is responsible for the phenomenon of mutarotation, the kinetics of which constitute one of the most interesting examples of general acid–base catalysis (cf. Brönsted and Guggenheim, *J. Amer. Chem. Soc.*, 1927, **49**, 2554; Lowry and Smith, J., 1927, 2539), and we might expect by analogy that the same kind of behaviour would be exhibited by the depolymerisation of the dimeric forms described above. The present paper describes a study of the depolymerisation kinetics in aqueous solutions of dihydroxyacetone, which is the most accessible of the substances mentioned.

Experimental.

Materials.—The dihydroxyacetone was a commercial product known as "oxantin," m. p. 77—84°, depending on the rate of heating. Previous values for the m. p. of the pure substance are 74—75° (Virtanen and Nordlund, *Biochem. J.*, 1933, **27**, 442), about 80° (Bertrand, *Ann. Chim. Phys.*, 1904, **3**, 253), and 68—75° (Piloty, *Ber.*, 1897, **30**, 3165), and it is probable that the indefinite m. p. is due to partial depolymerisation on melting. Treatment with a slight excess of 2 : 4-dinitrophenylhydrazine in 2N-hydrochloric acid gave an almost quantitative yield of hydrazone, m. p. 160°, raised to 161° by recrystallising twice from 50% methyl alcohol. Collatz and Neuberg (*Biochem. Z.*, 1930, **223**, 494) give 163° for the pure derivative. Finally, the oxantin did not react with bromine under the conditions given by Collatz and Neuberg (*loc. cit.*), and was therefore free from glyceraldehyde and similar substances. It thus appears to be fairly pure dihydroxyacetone, and since recrystallisation from acetone was very wasteful, it was used without further purification. It gave a neutral solution in water.

The acids used were mostly pure commercial products. Chloroacetic acid was purified by recrystallisation from benzene, and acrylic acid by fractional freezing. Trimethylacetic acid was prepared from pinacol and fractionated in a vacuum. The purity of the solid acids was checked by titration, values better than 99% of the theoretical being obtained in each case.

All solutions were made with water freed from carbon dioxide, and the acid solutions were

standardised directly against the sodium hydroxide solution used for making up the buffer solutions.

Measurement of Reaction Velocity.—It might be expected that the reaction shown in equation (1) would be accompanied by a considerable volume change, and it was in fact found that in aqueous solution the reaction from right to left results in an expansion of about 36 cu. mm. per g. of dihydroxyacetone. The reaction could thus be followed conveniently by a dilatometric method. Two dilatometers were used having severally volumes of 31 and 20 c.c. and capillaries of cross-section 0·233 and 0·105 sq. mm. The solutions used contained about 1% of dihydroxyacetone by weight, and the total movement obtained in the two capillaries was about 60 mm. and 100 mm. respectively. The experiments were carried out in a thermostat at $25° \pm 0·005°$, and the height of the meniscus could be read to the nearest 0·1 mm.

Dissolution of dihydroxyacetone in water is accompanied by a considerable heat absorption, and it is necessary to allow time for the solution to regain thermostat temperature before reliable readings can be obtained. In acid solutions of concentration about $4—8 \times 10^{-4}$ the depolymerisation is very slow (see below), and this fact was utilised in devising a method to enable fast reactions to be studied. 0·3—0·4 G. of dihydroxyacetone was dissolved in 10 c.c. of 6×10^{-4}N-hydrochloric acid at 25°, and the solution kept in the thermostat for 20 minutes. 25 C.c. of the catalysing solution (previously de-aerated and brought to thermostat temperature) were then added, and the mixed solution immediately transferred to the dilatometer. It was thus possible to obtain reliable readings 4—5 minutes after mixing. The acid present was allowed for in calculating the actual composition.

The course of the reaction was found to be strictly of the first order, and the velocity constants were calculated by Guggenheim's method (*Phil. Mag.*, 1926, **2**, 540), 30—60 readings being taken in each set. Table I gives the details of a typical experiment, the calculated values of Δx being given by the equation $\log_{10} \Delta x = 1·705 - 0·00812t$, where t is the time in minutes. In all the first-order velocity constants given, the time is measured in minutes and decadic logarithms are used. Concentrations are in g.-mols. per 1000 g. of solution.

Table I.

0·128N-*Mandelic acid* + 0·0980N-*sodium mandelate.*

Δt = 100 minutes.

(Only alternate readings are recorded.)

t.	Δx (mm.). Obs.	Calc.	Diff. (mm.).	t.	Δx (mm.). Obs.	Calc.	Diff. (mm.).	t.	Δx (mm.). Obs.	Calc.	Diff. (mm.).
10	41·8	42·1	− 0·3	42	23·2	23·1	+ 0·1	74	12·5	12·7	− 0·2
14	38·9	39·0	− 0·1	46	21·5	21·5	0·0	78	11·8	11·8	0·0
18	36·2	36·2	0·0	50	20·0	19·9	+ 0·1	82	10·9	10·9	0·0
22	33·5	33·6	− 0·1	54	18·4	18·5	− 0·1	86	10·1	10·1	0·0
26	31·1	31·2	− 0·1	58	17·1	17·1	0·0	90	9·6	9·3	+ 0·3
30	28·9	28·9	0·0	62	15·9	15·9	0·0	94	8·7	8·8	− 0·1
34	27·0	26·9	+ 0·1	66	14·9	14·8	+ 0·1	98	8·0	8·1	− 0·1
38	25·0	24·9	+ 0·1	70	13·7	13·7	0·0	100	7·7	7·7	0·0

In some cases when the solutions were allowed to remain in the dilatometer for several days, a very slow contraction was observed: this is probably due to the irreversible polymerisation of the dihydroxyacetone to higher sugars. This change was much too slow to interfere with the depolymerisation kinetics.

Results.

Hydrochloric Acid Solutions.—In the mutarotation of glucose there is a considerable range of hydrogen-ion concentrations over which catalysis by both hydrogen and hydroxyl ions can be neglected. Preliminary experiments with hydrochloric acid solutions of different concentrations showed that this is not the case with the present reaction, since the velocity passes through a fairly sharp minimum at about 6×10^{-4}N., rising very rapidly on the alkaline side of the minimum. Acid solutions more dilute than about 10^{-3}N. did not give completely reproducible results (presumably because of the large effect of small quantities of impurities), and Table II contains only results for higher concentrations than this, *i.e.*, well on the acid side of the minimum.

Table II.

[HCl] × 10^4	292	243	213	184	150	107	86·0	52·4	23·2
10^4k obs.	479	417	373	337	295	224	203	131	77·6
10^4k calc.	527	443	391	342	284	210	174	116	65·4

The relation between velocity constant and acid concentration is approximately linear, and when these are plotted there is a finite intercept at $[H_3O^+] = 0$. The value of this intercept is not given accurately by this set of experiments, but certainly lies between $k \times 10^4 = 20$ and 40. If we use the value $10^4k_0 = 25{\cdot}5$ derived later for the water catalysis, the results are best expressed by

$$k = 0{\cdot}00255 + 1{\cdot}72[H_3O^+] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

giving 1·72 as the mean value of the catalytic constant of the ion H_3O^+. The rates calculated from equation (2) are given in the third row of Table II. There is clearly a slight drift in catalytic constant with concentration, probably due to a primary salt effect, though the addition of 0·2M-sodium chloride has no appreciable effect on the velocity. (For a reaction involving an ion and a neutral molecule a specific salt effect is to be anticipated.)

Buffer Solutions.—In a buffer solution containing an uncharged acid A and the corresponding base B (*i.e.*, the anion of the acid) the general expression for the reaction velocity is

$$k = k_0 + k_{H_3O^+}[H_3O^+] + k_{OH^-}[OH^-] + k_A[A] + k_B[B] \quad . \quad . \quad . \quad . \quad (3)$$

where k_0 is the velocity of the water-catalysed reaction, and k_X is the catalytic constant of the species X. Equation (3) can be rewritten in the form

$$k = k' + \alpha[B] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

where $k' = k_0 + k_{H_3O^+}[H_3O^+] + k_{OH^-}[OH^-]$
and $\alpha = k_B + k_A[A]/[B]$

As stated above, there are no conditions under which it is possible to neglect the last two terms in k', and in order to derive values for the separate catalytic constants it is necessary to carry out series of experiments in which $[H_3O^+]$ and $[OH^-]$ are constant. This was effected by varying [A] and [B] but keeping the ratio [A]/[B] constant, and also keeping the total salt concentration constant at 0·1N. by adding sodium chloride when necessary. Under these conditions k' and α are constant for a given series and can be obtained graphically from the linear plot of k against [B]. Finally, by carrying out two or more such series with different values of [A]/[B], the separate values of k_B and k_A can be obtained. On account of the very

TABLE III.

Trimethylacetic acid; $k_B = 4{\cdot}2 \times 10^{-1}$.

[A]/[B] = 1·034, $[H_3O^+] = 1{\cdot}52 \times 10^{-5}$, $10^4k' = 456$.

[CMe₃·COO⁻]	0·0501	0·0398	0·0300	0·0225	0·0100
10^4k obs.	644	639	582	540	499
10^4k calc.	666	623	582	551	498

[A]/[B] = 1·795, $[H_3O^+] = 2{\cdot}64 \times 10^{-5}$, $10^4k' = 276$.

[CMe₃·COO⁻]	0·0305	0·0229	0·0151	0·00726
10^4k obs.	401	372	338	308
10^4k calc.	404	372	340	307

Acetic acid; $k_B = 1{\cdot}60 \times 10^{-1}$.

[A]/[B] = 0·980, $[H_3O^+] = 2{\cdot}69 \times 10^{-5}$, $10^4k' = 266$.

[CH₃·COO⁻]	0·1004	0·0505	0·0316	0·0129
10^4k obs.	424	350	318	284
10^4k calc.	427	347	317	287

[A]/[B] = 1·304, $[H_3O^+] = 3{\cdot}56 \times 10^{-5}$, $10^4k' = 217$.

[CH₃·COO⁻]	0·1045	0·0785	0·0533	0·0204
10^4k obs.	380	335	294	254
10^4k calc.	384	342	302	249

[A]/[B] = 3·38, $[H_3O^+] = 9{\cdot}27 \times 10^{-5}$, $10^4k' = 96{\cdot}0$.

[CH₃·COO⁻]	0·1027	0·0750	0·0409	0·0127
10^4k obs.	260	218	167	124
10^4k calc.	260	216	162	116

[A]/[B] = 4·83, $[H_3O^+] = 1{\cdot}32 \times 10^{-4}$, $10^4k' = 74{\cdot}0$.

[CH₃·COO⁻]	0·1026	0·0871	0·0683	0·0512	0·0303	0·0103
10^4k obs.	234	218	178	157	125	92·6
10^4k calc.	238	213	183	156	123	90·4

TABLE III (*continued*).

Phenylacetic acid; $k_B = 1{\cdot}22 \times 10^{-1}$.

$[A]/[B] = 0{\cdot}700$, $[H_3O^+] = 5{\cdot}32 \times 10^{-5}$, $10^4k' = 142$.

$[CH_2Ph{\cdot}COO^-]$	0·1036	0·0775	0·0514	0·0263
10^4k obs.	270	234	209	170
10^4k calc.	268	237	205	174

Acrylic acid; $k_B = 1{\cdot}15 \times 10^{-1}$.

$[A]/[B] = 0{\cdot}500$, $[H_3O^+] = 4{\cdot}34 \times 10^{-5}$, $10^4k' = 181$.

$[CH_2{:}CH{\cdot}COO^-]$	0·102	0·0668	0·0334
10^4k obs.	291	255	226
10^4k calc.	298	258	220

$[A]/[B] = 2{\cdot}50$, $[H_3O^+] = 2{\cdot}17 \times 10^{-4}$, $10^4k' = 60{\cdot}7$.

$[CH_2{:}CH{\cdot}COO^-]$	0·101	0·0667	0·0333
10^4k obs.	177	142	98·0
10^4k calc.	177	137	99·0

Formic acid; $k_A = 5{\cdot}4 \times 10^{-3}$; $k_B = 3{\cdot}21 \times 10^{-2}$.

$[A]/[B] = 0{\cdot}493$, $[H_3O^+] = 1{\cdot}36 \times 10^{-4}$, $10^4k' = 84{\cdot}0$.

$[H{\cdot}COO^-]$	0·1016	0·0710	0·0506	0·0205
10^4k obs.	119·5	108·7	101·2	91·2
10^4k calc.	119·3	108·7	101·6	91·1

$[A]/[B] = 1{\cdot}54$, $[H_3O^+] = 4{\cdot}26 \times 10^{-4}$, $10^4k' = 49{\cdot}1$.

$[H{\cdot}COO^-]$	0·0993	0·0743	0·0497	0·0245
10^4k obs.	90·1	79·0	69·6	59·0
10^4k calc.	89·3	79·1	69·2	59·0

$[A]/[B] = 3{\cdot}66$, $[H_3O^+] = 1{\cdot}01 \times 10^{-3}$, $10^4k' = 56{\cdot}2$.

$[H{\cdot}COO^-]$	0·1007	0·0760	0·0503	0·0247
10^4k obs.	108·3	95·4	82·2	71·4
10^4k calc.	108·9	95·6	82·2	68·9

Mandelic acid; $k_A = 1{\cdot}04 \times 10^{-2}$; $k_B = 2{\cdot}00 \times 10^{-2}$.

$[A]/[B] = 0{\cdot}129$, $[H_3O^+] = 7{\cdot}78 \times 10^{-5}$, $10^4k' = 106{\cdot}2$.

$[CHPh(OH){\cdot}COO^-]$	0·100	0·0750	0·0500	0·0250
10^4k obs.	130·3	122·0	120·2	110·6
10^4k calc.	127·5	122·2	116·9	111·6

$[A]/[B] = 0{\cdot}613$, $[H_3O^+] = 3{\cdot}70 \times 10^{-4}$, $10^4k' = 46{\cdot}7$.

$[CHPh(OH){\cdot}COO^-]$	0·0996	0·0747	0·0498	0·0249
10^4k obs.	73·4	66·3	61·4	52·5
10^4k calc.	73·0	66·4	59·8	53·3

$[A]/[B] = 1{\cdot}30$, $[H_3O^+] = 7{\cdot}82 \times 10^{-4}$, $10^4k' = 46{\cdot}1$.

$[CHPh(OH){\cdot}COO^-]$	0·0980	0·0735	0·0490	0·0245
10^4k obs.	81·2	70·6	62·0	55·6
10^4k calc.	78·9	70·7	62·5	54·6

Chloroacetic acid; $k_A = 1{\cdot}62 \times 10^{-2}$; $k_B = 6{\cdot}0 \times 10^{-3}$.

$[A]/[B] = 0{\cdot}200$, $10^4k' = 45{\cdot}3$.

$[CH_2Cl{\cdot}COO^-]$	0·1005	0·0753	0·0502	0·0251
$[H_3O^+] \times 10^4$	4·23	4·19	4·13	3·93
10^4k obs.	54·0	53·6	52·0	48·3
10^4k corr.	53·8	53·4	51·6	47·5
10^4k calc.	54·5	52·2	49·9	47·6

$[A]/[B] = 0{\cdot}800$, $10^4k' = 63{\cdot}3$.

$[CH_2Cl{\cdot}COO^-]$	0·0994	0·0745	0·0497	0·0248
$[H_3O^+] \times 10^3$	1·69	1·67	1·64	1·55
10^4k obs.	82·2	79·6	72·4	65·4
10^4k corr.	82·8	80·5	73·9	68·4
10^4k calc.	82·0	77·4	72·7	68·0

$[A]/[B] = 1{\cdot}40$, $10^4k' = 90{\cdot}1$.

$[CH_2Cl{\cdot}COO^-]$	0·0937	0·0703	0·0468	0·0234
$[H_3O^+] \times 10^3$	2·93	2·89	2·83	2·64
10^4k obs.	114·4	108·4	99·2	89·8
10^4k corr.	116·1	110·9	102·8	97·0
10^4k calc.	117·0	110·3	103·5	96·8

TABLE III (*continued*).

Cyanoacetic acid; $k_A = 3{\cdot}2 \times 10^{-2}$.

			10^4k		
$[CH_2(CN)\cdot CO_2H]$.	$[CH_2(CN)\cdot COO^-]$.	$[H_3O^+] \times 10^4$.	Obs.	Corr.	Calc.
0·0498	0·0996	26·4	92·8	40·4	41·5
0·0374	0·0747	25·9	88·2	36·8	37·5
0·0299	0·0996	15·9	68·2	35·2	35·1
0·0224	0·0747	15·6	65·2	33·5	32·7
0·0149	0·0498	15·3	61·0	31·2	30·3
0·0102	0·102	5·38	51·9	29·4	28·8
0·00752	0·0752	5·31	49·5	27·0	27·9

great catalytic effect of the hydroxyl ion, it was necessary in most cases to keep the hydrogen-ion concentration greater than about 10^{-4}: this restricted the choice of acids to those readily soluble in water.

The results for buffer solutions are given in Table III. For trimethylacetic, acetic, phenylacetic, acrylic, formic, and mandelic acids the results were treated as described above, and the values of k_A and k_B obtained are given at the head of each section. The calculated values of k were obtained by inserting these values of k_A and k_B and the observed values of k' in equation (4). In the case of trimethylacetic, acetic, and acrylic acids no acid catalysis could be detected, the value of α being sensibly the same for different values of [A]/[B]. On account of the limited solubility of phenylacetic acid it was not feasible to vary [A]/[B] over any considerable range, but we may assume that catalysis by undissociated acid can also be neglected in this case.

With chloroacetic acid it is necessary to allow for the fact that the actual value of [A]/[B] differs appreciably from the stoicheiometric ratio and changes slightly when the buffer is diluted. The hydrogen-ion concentration is therefore not quite constant in each series, the actual values being given in the table. The values of k (corr.) represent the velocity constants which would be obtained if [A]/[B] were constant and equal to the stoicheiometric ratio in each series: in applying the correction only the values of $k_{H_3O^+}$ and k_{OH^-} are needed, since the variations in the catalytic effect of the other species are negligible. The corrected values are then treated as described above. The methods of calculating $[H_3O^+]$, $[OH^-]$, and k_{OH^-} are given below.

These corrections are negligible for the weaker acids studied, but they are still larger for the stronger cyanoacetic acid, and it is not possible to obtain a reliable value for the small catalytic effect of the cyanoacetate ion. The values of k (corr.) in the table were obtained by subtracting from the observed velocity the calculated velocities due to the ions H_3O^+ and OH^-, and the calculated velocity constants are given by

$$k = 0{\cdot}00255 + k_A[A] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

the catalysis by $CH_2(CN)\cdot COO^-$ being assumed to be negligible.

The values of k' correspond to catalysis by H_2O, OH^-, and H_3O^+, and it is clear from the results in acid solutions that the last of these three can be neglected when $[H_3O^+] < ca.\ 10^{-4}$. The values of k' for buffers in this range can therefore be used to obtain values of k_{OH^-} and k_0. The concentrations of hydrogen and hydroxyl ions in these buffers are given by the equations

$$[H_3O^+] = f_A[A]K_A/f_Bf_{H_3O^+}[B]; \qquad [OH^-] = K_w'/[H_3O^+] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

where K_w' is the ionic product of water at an ionic strength of 0·1 and K_A is the thermodynamic dissociation constant of the acid. In most cases [A]/[B] can be taken as the stoicheiometric buffer ratio, but for chloro- and cyano-acetic acids the mass-action equation must be solved. Harned and Hamer (*J. Amer. Chem. Soc.*, 1933, **55**, 2198) give $1{\cdot}61 \times 10^{-14}$ for K_w' in 0·1N-sodium chloride at 25°, and this value has been used throughout. Larsson and Adell (*Z. physikal. Chem.*, 1931, **156**, *A*, 352, 381) have measured the value of $f_Bf_{H_3O^+}/f_A$ for ten carboxylic acids in 0·1N-sodium chloride, and find values which are all within a few units % of 0·641: this value has therefore been used in calculating all the hydrogen- and hydroxyl-ion concentrations. (The previous treatment has been based on the assumption that the activity coefficients depend only on the total concentration of uni-univalent salt, and not on the nature of the other ions present: hence there is no point in attempting to distinguish between values in NaCl and in NaB.) The calculated values of $[H_3O^+]$ are given in Table III, and Table IV

contains the values of $[H_3O^+]$, $[OH^-]$, and k' for buffers of $p_H > 4$. The values of K_A used, together with their sources, are given in Table V. The results are well represented by the equation

$$k' = 0{\cdot}00255 + 4{\cdot}03 \times 10^7[OH^-] \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

which is the basis of the calculated values in the table. This gives an accurate value for k_{OH^-}, and a value for k_0 which is consistent with the results in hydrochloric acid solutions and in cyanoacetate buffers.

TABLE IV.

Acid.	[A]/[B].	$[H_3O^+] \times 10^6$.	$[OH^-] \times 10^{10}$.	$10^4k'$. Obs.	$10^4k'$. Calc.
Trimethylacetic	1·034	1·52	10·64	456	455
,,	1·795	2·64	6·12	276	273
Acetic	0·980	2·69	6·00	266	268
,,	1·304	3·56	4·53	217	210
,,	3·38	9·27	1·74	96·0	96·2
Phenylacetic	0·700	5·32	3·04	142	148
Acrylic	0·500	4·34	3·73	181	176
Mandelic	0·129	7·78	2·08	106	110

For the other buffer solutions both hydrogen- and hydroxyl-ion catalysis contribute to k'. The observed values show good general agreement (to within 10%) with the equation

$$k' = 0{\cdot}00255 + 1{\cdot}72[H_3O^+] + 4{\cdot}03 \times 10^7[OH^-] \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

[cf. equations (2) and (7)]: this is as close as can be expected in view of the simplifying assumptions made about the activity coefficients. The value of k' passes through a minimum at about $[H_3O^+] = 6 \times 10^{-4}$, where its value is about 0·0046, *i.e.*, nearly twice the "spontaneous" rate k_0 due to catalysis by water molecules. It may be noted that the value derived for k_{OH^-} depends on the figure chosen for the activity coefficient factor in equation (6), while the other catalytic constants are independent of this choice.

DISCUSSION OF RESULTS.

The above results show that the depolymerisation of dimeric dihydroxyacetone is subject to general catalysis by both acids and bases, like the analogous mutarotation reaction. Table V gives the catalytic constants of the different species studied, together with the acid dissociation constants K_A. The figure shows a plot of $\log_{10} k_A$ and $\log_{10} k_B$ against $\log_{10} K_A$ for the carboxylic acids and their anions.

TABLE V.

Acid.	Base.	k_A.	k_B.	K_A.
H_2O	OH^-	$(4{\cdot}6 \times 10^{-5})$	$3{\cdot}03 \times 10^{-7}$	$1{\cdot}79 \times 10^{-16}$
$CMe_3{\cdot}CO_2H$	$CMe_3{\cdot}COO^-$	—	$4{\cdot}20 \times 10^{-1}$	$9{\cdot}40 \times 10^{-6}$ (*a*)
$CH_3{\cdot}CO_2H$	$CH_3{\cdot}COO^-$	—	$1{\cdot}60 \times 10^{-1}$	$1{\cdot}75 \times 10^{-5}$ (*b*)
$CH_2Ph{\cdot}CO_2H$	$CH_2Ph{\cdot}COO^-$	—	$1{\cdot}22 \times 10^{-1}$	$4{\cdot}88 \times 10^{-5}$ (*c*)
$CH_2{:}CH{\cdot}CO_2H$	$CH_2{:}CH{\cdot}COO^-$	—	$1{\cdot}15 \times 10^{-1}$	$5{\cdot}56 \times 10^{-5}$ (*d*)
$H{\cdot}CO_2H$	$H{\cdot}COO^-$	$5{\cdot}4 \times 10^{-3}$	$3{\cdot}21 \times 10^{-2}$	$1{\cdot}77 \times 10^{-4}$ (*e*)
$CHPh(OH){\cdot}CO_2H$	$CHPh(OH){\cdot}COO^-$	$1{\cdot}04 \times 10^{-2}$	$2{\cdot}00 \times 10^{-2}$	$3{\cdot}86 \times 10^{-4}$ (*f*)
$CH_2Cl{\cdot}CO_2H$	$CH_2Cl{\cdot}COO^-$	$1{\cdot}62 \times 10^{-2}$	$6{\cdot}0 \times 10^{-3}$	$1{\cdot}38 \times 10^{-3}$ (*g*)
$CH_2(CN){\cdot}CO_2H$	$CH_2(CN){\cdot}COO^-$	$3{\cdot}2 \times 10^{-2}$	—	$3{\cdot}56 \times 10^{-3}$ (*h*)
H_3O^+	H_2O	$1{\cdot}72$	$(4{\cdot}6 \times 10^{-5})$	$5{\cdot}55 \times 10$

(*a*) Larsson and Adell, *loc. cit.*, p. 352; (*b*) Harned and Ehlers, *J. Amer. Chem. Soc.*, 1933, **55**, 652; (*c*) Jeffery and Vogel, J., 1934, 166; (*d*) Dippy and Lewis, this vol., p. 1008; (*e*) Harned and Embree, *J. Amer. Chem. Soc.*, 1934, **56**, 1042; (*f*) Davies, private communication; (*g*) Wright, *J. Amer. Chem. Soc.*, 1934, **56**, 314; (*h*) Davies, *Phil. Mag.*, 1927, **4**, 244.

The straight lines in the figure represent the equations

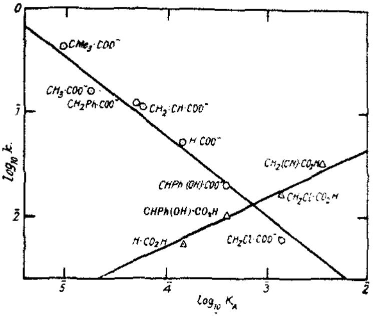
$$k_A = 0{\cdot}20K_A^{0{\cdot}38} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

and

$$k_B = 5{\cdot}0 \times 10^{-5}(1/K_A)^{0{\cdot}76} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

the exact values of the constants having been chosen so as to agree with the results for the ions H_3O^+ and OH^- respectively. The figure shows that this choice of constants

agrees well with the results for anion catalysis, and is consistent with the somewhat meagre data for catalysis by acid molecules. The Brönsted equation thus appears to be obeyed over ranges of 13 and 5 powers of ten for basic and acid catalysis respectively.



The values predicted by equations (9) and (10) for trimethylacetic, acetic, and acrylic acids and the cyanoacetate ion are consistent with the failure to detect catalysis by these species under the conditions of experiment.

The catalytic constant for water molecules was obtained by dividing the "spontaneous" rate k_0 by 55·5, and its interpretation offers a special point of interest. The only other reactions in which general catalysis by both acids and bases has been studied are the mutarotation of glucose (Brönsted and Guggenheim, *loc. cit.*) and the acetone–iodine reaction (Dawson *et al.*, J., 1926—1936), and in both cases it is clear from the results with other catalysts that the acid catalysis by water molecules is negligible compared with the basic catalysis. In the present case, however, the values of k_A and k_B calculated from equations (9) and (10) are of the same order of magnitude, so that we cannot exclude the possibility that both types of catalysis contribute to the observed "spontaneous" rate, especially as the observed value of $k_0/55{\cdot}5$ is considerably greater than the calculated value of either k_A or k_B.

The exponent of the Brönsted equation has the value 0·38 for acid catalysis, which is not far different from the value 0·3 found for the mutarotation of glucose. For basic catalysis, on the other hand, the exponents for the two reactions are 0·76 and 0·34 respectively: this large difference may be related to the fact that the dihydroxyacetone ring contains two oxygen atoms, whereas the glucose ring contains only one. It is interesting to note that the velocity is throughout proportional to the first power of the catalyst concentration, in spite of the fact that the depolymerisation involves the fission of the ring at two points. In the depolymerisation of paraldehyde (involving the fission of a similar ring at three points) the catalyst concentration appears to enter to a power higher than the first (cf. Bell, Lidwell, and Vaughan-Jackson, J., 1936, 1792).

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411. *Some Derivatives of Diphenylamine and a New Synthesis of* N-*Aryl-anthranilic Acids and of Acridones.*

By MARGARET M. JAMISON and E. E. TURNER.

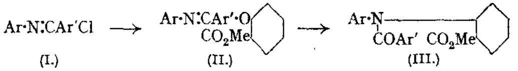
The main subject dealt with is a new synthesis of substituted diphenylamine-2-carboxylic acids, which are important because of their ready cyclisation to acridones or 5-chloroacridines, from which antimalarial drugs are derived.

DURING an extended stereochemical study of derivatives of tervalent nitrogen, we have had occasion to prepare a number of new substituted diphenylamines. By straightforward application of the convenient method of Chapman (J., 1929, 569 and previous papers) we have obtained 2 : 4'-*dichloro*-, 2 : 4 : 4'-*trichloro*-, 2 : 4 : 6 : 2' : 4'-*pentachloro*- and 4-*chloro*-4'-*bromo-diphenylamine*. These substances could not be caused to react with *p*-toluenesulphonyl chloride, even in presence of quinoline at high temperatures, and while *p*-chloro- and 2 : 4'-dichloro-diphenylamine were found to give N-*nitroso*-derivatives, under the conditions used by Fischer for nitrosating diphenylamine (*Annalen*, 1878, **190**, 175), pentachlorodiphenylamine could not be induced to react with nitrous acid or its esters in any of the circumstances which seemed likely to favour reaction. Similarly, the pentachloro-compound was indifferent to carbonyl chloride at high temperatures, whereas the trichloro-compound reacted readily with it at 140—150°. This method of preparation of 2 : 4 : 4'-*trichlorodiphenylcarbamyl chloride* has incidentally been applied to the preparation of diphenylcarbamyl chloride itself, which substance is obtainable far more readily by the new process than by those described in the literature (Erdmann and Huth, *J. pr. Chem.*, 1897, **56**, 7; D.R.-P. 285,134).

By reduction of the *N*-nitroso-derivatives of *p*-chloro- and 2 : 4'-dichloro-diphenylamine, we have prepared 4-*chloro*- and 2 : 4'-*dichloro*-NN-*diphenylhydrazine*, but the difficulty of effecting such reductions made a proposed study of the hydrazines impossible.

For another section of the investigation, we required substituted diphenylamine-carboxylic acids. Some of these acids are readily obtainable by condensing anthranilic acids with halogeno-derivatives of aromatic hydrocarbons (Goldberg and Nimerowsky, *Ber.*, 1907, **40**, 2449) or *o*-halogenobenzoic acids with aromatic bases (Ullmann, *Annalen*, 1907, **355**, 312), but of these four types only the last-named permits of much variation. We have found that the Chapman diphenylamine synthesis can be applied to the preparation of *N*-arylanthranilic acids, and the method is available also for obtaining *N*-aroyl-*N*-arylanthranilic acids, which cannot be produced by direct *N*-aroylation.

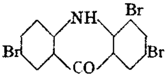
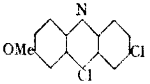
The readily accessible imino-chlorides (I) react almost quantitatively with the sodium derivatives of esters of salicylic acids, and the ethers (II) formed undergo the Chapman



(I.) (II.) (III.)

conversion with unusual ease, to give the aroylarylanthranilic esters (III). The change (II) ⟶ (III) usually occurs at about 270°, and is markedly exothermic, the temperature rising spontaneously as much as 30°, the rise depending partly on the scale of the operation. None of Chapman's recorded changes showed this exothermic effect, which is no doubt due to the acceleration of the process by the carbalkoxy-group, Chapman having already shown (J., 1927, 1743) that the isomerisation of imino-ethers in general is promoted by the presence of an electron-attracting group in the migrating nucleus. Hydrolysis of esters of type (III) proceeds quantitatively, and in this way diphenylamine-2-carboxylic acid and its 4'-chloro-, 2' : 4'-dichloro-, 4 : 6 : 4'-*tribromo*-, 4-chloro-4'-methoxy- and 2' : 4'-*dimethyl*- derivatives have been obtained. Former syntheses would have failed in the case of the tribromo-acid, and the present synthesis thus makes possible the preparation of a number of new acridones and the corresponding 5-chloroacridines. From the tribromo-acid, 1 : 3 : 7-*tribromoacridone* (IV) has been obtained by the phosphoryl chloride method of

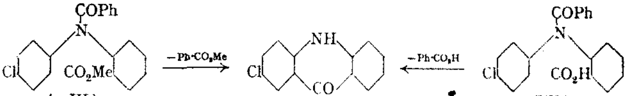
Drosdov (*J. Gen. Chem. Russ.*, 1934, **4**, 117). Feldman and Kopeliovitsch (*Arch. Pharm.*, 1935, **273**, 488), in studies of substances resembling "atebrin," prepared 3 : 5-dichloro-7-methoxyacridine (V) from 4-chloro-4'-methoxydiphenylamine-2-carboxylic acid, but their

(IV.)   (V.)

synthesis, of the Ullmann type, necessitates the use of the difficultly accessible 2 : 5-dichlorobenzoic acid.

All the *N*-arylanthranilic acids obtained by the new method are free from the impurities which appear to be unavoidable in the products of the older syntheses.

Some methyl esters of type (III) (Ar' = Ph) lose methyl benzoate when heated and pass



(as III.) (VI.) (VII.)

into the corresponding acridones (VI), although not quantitatively. The one *l*-menthyl ester examined gave *l*-menthene, benzoic acid and the acridone.

Partial hydrolysis of the esters (III) is readily effected. Some of the *N*-aroyl-*N*-arylanthranilic acids (VII) so obtained lose benzoic acid when they are heated for a few minutes and again an acridone is formed. This is actually one of the most expeditious methods of obtaining an acridone, as the yields are good and the product is easily purified. Curiously enough, *N*-benzoyl-*N*-phenylanthranilic acid does not undergo this conversion into acridone at temperatures up to 350°.

Substituted diphenylamine-4-carboxylic acids are readily obtained from *p*-hydroxybenzoic esters.

Experimental.

Preparation of Halogenodiphenylamines.—The experimental procedure described by Chapman (*loc. cit.*) was followed without modification.

N-o-*Chlorophenylbenzimino*-p-*chlorophenyl ether*, large irregular crystals from alcohol, has m. p. 59—60° (Found : Cl, 20·9. $C_{19}H_{13}ONCl_2$ requires Cl, 20·8%). Yield, 90%.

N-*Benzoyl*-2 : 4'-*dichlorodiphenylamine* was formed in 74% yield when the last-named compound was heated at 300° for 2 hours. It crystallised from alcohol in prisms, m. p. 115° (Found : Cl, 20·8. $C_{19}H_{13}ONCl_2$ requires Cl, 20·8%).

2 : 4'-*Dichlorodiphenylamine*, large prisms from alcohol, has m. p. 42° (Found : Cl, 30·3. $C_{12}H_9NCl_2$ requires Cl, 29·8%). Yield, 71%.

N-2 : 4-*Dichlorophenylbenzimino*-p-*chlorophenyl ether* crystallised from alcohol in hexagonal plates, m. p. 81° (Found : Cl, 28·1. $C_{19}H_{12}ONCl_3$ requires Cl, 28·3%). Yield, 96%.

N-*Benzoyl*-2 : 4 : 4'-*trichlorodiphenylamine*, formed in 76% yield by heating the preceding ether for 2 hours at 250—270°, separated from light petroleum (b. p. 80—100°) in rhombs, m. p. 117—118° (Found : Cl, 28·5. $C_{19}H_{12}ONCl_3$ requires Cl, 28·3%).

2 : 4 : 4'-*Trichlorodiphenylamine* crystallised from light petroleum (b. p. 60—80°) in angular plates, m. p. 67—68° (Found : Cl, 39·1. $C_{12}H_8NCl_3$ requires Cl, 39·3%). Yield, 85%.

N-*p*-Chlorophenyl-*p*-toluimino-2 : 4-dichlorophenyl ether, $C_6H_4Cl{\cdot}N{:}C(C_6H_4Me){\cdot}O{\cdot}C_6H_3Cl_2$, was prepared from 2 : 4-dichlorophenol and *N*-*p*-chlorophenyl-*p*-toluanilideiminochloride, the latter being obtained by the action of phosphorus pentachloride on *p*-tolu-*p*-chloroanilide. The ether was an uncrystallisable glass.

N-p-*Toluoyl*-2 : 4 : 4'-*trichlorodiphenylamine* was obtained by heating the above glass for 2·5 hours at 280—300°. The black glass which resulted was crystallised from light petroleum (b. p. 80—100°), then twice from alcohol, and finally from glacial acetic acid. The p-*toluoyl* derivative formed irregular prisms, m. p. 157° (Found : Cl, 27·2. $C_{20}H_{14}ONCl_3$ requires Cl, 27·3%).

N-p-*Chlorophenylbenzimino-2′-(carbo-l-menthoxy)phenyl ether* was obtained as an uncrystallisable glass (yield, 88%) from benz-*p*-chloroanilideiminochloride and *l*-menthyl salicylate. When heated at 280—295°, it passed into *N*-benzoyl-4-chloro-2′-(carbo-*l*-menthoxy)diphenylamine, but this at once began to decompose, giving (1) *l*-menthene, b. p. 165°, (2) benzoic acid, and (3) 3-chloroacridone.

N-2 : 4-*Dichlorophenylbenzimino-2 : 4 : 6-trichlorophenyl ether* separated from alcohol in prisms, m. p. 86—88° (Found : Cl, 39·9. $C_{19}H_{10}ONCl_5$ requires Cl, 39·8%). Yield, 88%.

N-*Benzoyl-2 : 4 : 6 : 2′ : 4′-pentachlorodiphenylamine*, formed in 81% yield by heating the preceding ether for 2 hours at 250—270°, crystallised from alcohol in prisms, m. p. 160° (Found : Cl, 39·6. $C_{19}H_{10}ONCl_5$ requires Cl, 39·8%).

2 : 4 : 6 : 2′ : 4′-*Pentachlorodiphenylamine* crystallised from alcohol in slender needles, m. p. 94° (Found : Cl, 51·6. $C_{12}H_6NCl_5$ requires Cl, 51·9%). Yield, 92%. The *N*-nitroso-derivative could not be obtained by using (*a*) sodium nitrite and hydrochloric acid in alcoholic solution, (*b*) amyl nitrite and hydrochloric acid in glacial acetic acid solution, (*c*) sodium nitrite and concentrated sulphuric acid.

N-p-*Bromophenylbenzimino-p-chlorophenyl ether* separated from alcohol in prisms, m. p. 83—84° (0·1698 gave 0·1449 AgCl + AgBr. $C_{19}H_{13}ONClBr$ requires 0·1449 AgCl + AgBr).

N-*Benzoyl-4-chloro-4′-bromodiphenylamine*, obtained in 75% yield by heating the last-named ether for 2·5 hours at 290—320°, crystallised from alcohol in plates, m. p. 149° (0·1424 gave 0·1194 AgCl + AgBr. $C_{19}H_{13}ONClBr$ requires 0·1249 AgCl + AgBr).

4-*Chloro-4′-bromodiphenylamine* formed plates, m. p. 91·5°, from alcohol (0·1272 gave 0·1477 AgCl + AgBr. $C_{12}H_9NClBr$ requires 0·1489 AgCl + AgBr).

N-*Nitroso-p-chlorodiphenylamine* crystallised from light petroleum (b. p. 40—60°) in prisms, m. p. 88° (Found : Cl, 15·0. $C_{12}H_9ON_2Cl$ requires Cl, 15·3%). Yield, 83%.

N-*Phenyl*-N-p-*chlorophenylhydrazine*, prepared by reducing the above nitroso-compound with zinc dust and aqueous alcoholic acetic acid by the Fischer method (*loc. cit.*), contained a high proportion of *p*-chlorodiphenylamine, which survived the usual hydrochloride separation. By crystallising the acid oxalate this difficulty was avoided, and the *hydrazine* was obtained as a pale golden oil, b. p. 194°/2 mm. (Found : Cl, 16·1. $C_{12}H_{11}N_2Cl$ requires Cl, 16·2%).

N-*Nitroso-2 : 4′-dichlorodiphenylamine* formed yellow needles, m. p. 66—67°, from light petroleum (b. p. 60—80°) (Found : Cl, 26·6. $C_{12}H_8ON_2Cl_2$ requires Cl, 26·6%). Yield, 82%.

2 : 4′-*Dichloro*-NN-*diphenylhydrazine*.—The preceding nitroso-compound was reduced with zinc dust and aqueous alcoholic acetic acid. The resulting paste was extracted with alcohol. The extract was treated with concentrated hydrochloric acid. The crystalline material precipitated was shaken with a mixture of water and light petroleum, whereupon dichlorodiphenylamine passed into the latter and the aqueous layer yielded almost pure *dichlorodiphenylhydrazine*. This was a pale yellow oil, b. p. 241°/8 mm. (Found : Cl, 28·9. $C_{12}H_{10}N_2Cl_2$ requires Cl, 28·1%). Yield, 25%.

N-2-*Chlorophenyl*-N-4-*chlorophenyl*-N′N′-4-*chlorophthalylhydrazine*,

$$N(C_6H_4Cl)(C_6H_4Cl)\cdot N{:}C_2O_2{:}C_6H_3Cl.$$

—Equimolecular quantities of 2 : 4′-dichlorodiphenylhydrazine and 4-chlorophthalic anhydride were heated at 170—190° for an hour. Alcohol was added, the mixture boiled for an hour, the alcohol evaporated, and the residual powder ground with dilute sodium carbonate solution. The *chlorophthalyl* derivative left crystallised from alcohol in yellow clusters of needles, m. p. 142—142·5° (Found : Cl, 25·2. $C_{20}H_{11}O_2N_2Cl_3$ requires Cl, 25·5%).

2 : 4 : 4′-*Trichlorodiphenylcarbamyl Chloride*.—Carbonyl chloride was bubbled through 10 g. of 2 : 4 : 4′-trichlorodiphenylamine at 150—200° until no further increase in weight occurred (about 30 minutes). When the cooled product was crystallised from alcohol, the *chloride* was obtained in needles, m. p. 117—118° (Found : Cl, 42·3. $C_{13}H_7ONCl_4$ requires Cl, 42·4%). Yield, 68%.

Diphenylcarbamyl chloride was obtained similarly (temperature, 140—150°; 15 minutes; yield, 92%).

N-p-*Chlorophenylbenzimino-o-carbomethoxyphenyl Ether*.—To a cooled solution of sodium (14·5 g.; 1·25 atoms) in 700 c.c. of absolute alcohol were added in rapid succession (1) 114 g. (1·5 mols.) of methyl salicylate and (2) 130 g. (1 mol.) of benz-*p*-chloroanilideiminochloride, dissolved in dry ether. The mixture became cloudy, and was kept overnight. The ether and most of the alcohol were then removed by evaporation, and water added. The *ether* became solid; it crystallised from alcohol in angular plates, m. p. 130—131° (Found : Cl, 9·9. $C_{21}H_{16}O_3NCl$ requires Cl, 9·7%). Yield, 166 g. (88%).

Methyl N-*Benzoyl-4-chlorodiphenylamine-2′-carboxylate*.—The above imino-ether (30 g.)

was heated in a wide tube in a bath kept at 270—275°. As soon as the temperature inside the tube attained that of the bath, isomeric change began, and the internal temperature rose to about 300° within a few minutes. When it began to fall, the product was poured into alcohol (2 vols.). On cooling, the *methyl* ester separated in prisms, m. p. 139—140° (Found: Cl, 9·5. $C_{21}H_{16}O_3NCl$ requires Cl, 9·7%). Yield of pure substance, 85—91%.

When the ester was heated at 320°, methyl benzoate (b. p. 199°) distilled, and 3-chloroacridone was formed. The latter crystallised from *cyclo*hexanol in yellow needles, m. p. above 360° (compare Ullmann, *loc. cit.*) (Found: Cl, 15·4. Calc.: Cl, 15·4%).

N-*Benzoyl-4-chlorodiphenylamine-2′-carboxylic Acid.*—For this, and similar partial hydrolyses of esters of *N*-benzoyl derivatives, it was convenient to have ready a solution (*S*) made by dissolving 2·3 g. of sodium in 100 c.c. of absolute alcohol, and adding 20 c.c. of water. A solution containing the methyl ester (11 g.; 1 mol.), 60 c.c. of absolute alcohol, 33 c.c. of solution *S* (equivalent to 1 atom of sodium), and 33 c.c. of water was boiled under reflux for an hour. The alcohol was evaporated, and the residue acidified with hydrochloric acid. The precipitate was extracted with sodium hydrogen carbonate solution, and the filtered extract acidified. The precipitate was freed from benzoic acid by extraction with boiling water, dried, and crystallised from acetone–light petroleum (b. p. 40—60°). It formed needles, m. p. 191—192° (Found: Cl, 10·2. $C_{20}H_{14}O_3NCl$ requires Cl, 10·1%). Yield, 8 g. (76%).

Action of Heat on the Preceding Acid.—The acid was heated rapidly to 250° during 5 minutes. The resulting mixture was freed from benzoic acid by extraction with boiling water, and 3-chloroacridone obtained in 90% yield.

4-*Chlorodiphenylamine-2′-carboxylic Acid.*—A solution of methyl *N*-benzoyl-4-chlorodiphenylamine-2′-carboxylate (10 g.) in 125 c.c. of alcohol was treated with 40 g. of sodium hydroxide in 40 c.c. of water, and the whole then boiled under reflux for an hour. The alcohol was evaporated, and the aqueous solution acidified with hydrochloric acid. The precipitate was freed from benzoic acid by extraction with boiling water; the residual carboxylic acid crystallised from alcohol in pale yellow prisms, m. p. 177—178° (Ullmann, *loc. cit.*, gives 177°; the product obtained by the Ullmann method was less easily purified). Yield, almost theoretical. The acid was readily converted into 3-chloroacridone by Drosdov's method (*loc. cit.*). Yield, 87%.

N-2 : 4-*Dichlorophenylbenzimino-o-carbomethoxyphenyl ether*, obtained from benz-2 : 4-dichloroanilideiminochloride and methyl salicylate in 72% yield, crystallised from alcohol in needles, m. p. 85—87° (Found: Cl, 17·6. $C_{21}H_{15}O_3NCl_2$ requires Cl, 17·7%).

Methyl N-*benzoyl*-2 : 4-*dichlorodiphenylamine*-2′-*carboxylate* was obtained in 65% yield by heating the last-named ether at 260—280° for 10 minutes. It formed rods, m. p. 114—116°, from ethyl alcohol (Found: Cl, 17·6. $C_{21}H_{15}O_3NCl_2$ requires Cl, 17·7%).

N-*Benzoyl*-2 : 4-*dichlorodiphenylamine*-2′-*carboxylic acid* was obtained by partial hydrolysis of the benzoyl-methyl ester. After being dissolved in sodium bicarbonate solution and precipitated therefrom with acid, it was hydrated, and therefore was dried in a high vacuum over phosphoric oxide (Found: Cl, 18·5. $C_{20}H_{13}O_3NCl_2$ requires Cl, 18·4%). The acid crystallised from benzene or from light petroleum–acetone in needles, solvated in both cases. The product from the second solvent had m. p. 177°.

2′ : 4′-*Dichlorodiphenylamine*-2-*carboxylic Acid.*—The benzoyl ester was hydrolysed with excess of alcoholic sodium hydroxide. The crude acid obtained (93% yield) had m. p. 243° (Ullmann, *loc. cit.*, gave 249° for the pure acid).

4-m-*Xylylbenzimino*-2′-*carbomethoxyphenyl ether*, formed from benz-4-*m*-xylidideiminochloride in 56% yield, crystallised from alcohol in rectangular prisms, m. p. 87—88° (Found: C, 76·7; H, 6·0. $C_{23}H_{21}O_3N$ requires C, 76·85; H, 5·9%).

Methyl N-*benzoyl*-2 : 4-*dimethyldiphenylamine*-2′-*carboxylate* was formed in 89% yield by heating the preceding ether at 275° for 10 minutes, and crystallised from methyl alcohol in stout prisms, m. p. 132—133° (Found: C, 76·7; H, 5·7. $C_{23}H_{21}O_3N$ requires C, 76·85; H, 5·9%). The ester showed no tendency to give the corresponding acridone when heated at 350°.

N-*Benzoyl*-2 : 4-*dimethyldiphenylamine*-2′-*carboxylic acid*, obtained by hydrolysing the methyl ester, crystallised from acetone–light petroleum (b. p. 40—60°) in prisms, softening at 191°, and melting at 192—193° (Found: C, 76·4; H, 5·6. $C_{22}H_{19}O_3N$ requires C, 76·5; H, 5·7%). Yield, 74%.

Action of Heat on the Preceding Acid.—The acid was heated for a few minutes at 300°. The residue was extracted with boiling alcohol, 1 : 3-dimethylacridone being left as small yellow needles, m. p. 307°. Yield, 71%.

N-*Phenylbenzimino-o-carbomethoxyphenyl ether*, obtained from benzanilideiminochloride

and methyl salicylate in 81% yield, formed rhombohedra, m. p. 110—111°, from alcohol (Found: C, 76·2; H, 5·1. $C_{21}H_{17}O_3N$ requires C, 76·1; H, 5·2%).

Methyl N-*benzoyldiphenylamine-2-carboxylate* was formed in 73% yield by heating the last-named ether at 270—275° for 10 minutes. It crystallised from alcohol in diamond-shaped prisms, m. p. 132—133° (Found: C, 75·9; H, 4·9. $C_{21}H_{17}O_3N$ requires C, 76·1; H, 5·2%). Hydrolysis of the ester with excess of alcoholic alkali gave *N*-phenylanthranilic acid in 96% yield.

N-*Benzoyl*-N-*phenylanthranilic* [N-*benzoyldiphenylamine-2-carboxylic*] *acid*, obtained from its methyl ester in 76% yield, was crystallised from acetone–light petroleum (b. p. 40—60°) and then from benzene. It formed slender needles, m. p. 186° (Found: C, 75·7; H, 5·0. $C_{20}H_{15}O_3N$ requires C, 75·7; H, 4·8%).

N-p-*Bromophenylbenzimino-4′ : 6′-dibromo-2′-carbomethoxyphenyl Ether*.—Sodium (3·7 g.; 1·25 atoms) was dissolved in 150 c.c. of absolute alcohol, and a suspension of 50 g. (1·5 mols.) of methyl 3 : 5-dibromosalicylate in 100 c.c. of alcohol added, followed by a solution of 47 g. of benz-*p*-bromoanilideiminochloride in dry ether. The mixture was shaken for a few minutes and left overnight. Most of the solvents were removed by evaporation, and the white oil extracted with warm water until it became a solid. This crystallised from alcohol in long prisms, m. p. 105° (Found: Br, 42·8. $C_{21}H_{14}O_3NBr_3$ requires Br, 42·2%). Yield, 65%.

Methyl N-*benzoyl-4 : 6 : 4′-tribromodiphenylamine-2-carboxylate*, obtained in 87% yield by heating the preceding ether at 270°, formed small prisms, m. p. 138—139°, from alcohol (Found: Br, 42·8. $C_{21}H_{14}O_3NBr_3$ requires Br, 42·2%).

N-*Benzoyl-4 : 6 : 4′-tribromodiphenylamine-2-carboxylic acid*, obtained from its methyl ester, crystallised from acetone–light petroleum (b. p. 40—60°) in slender prisms, m. p. 217—218° (with previous softening) (Found: Br, 42·6. $C_{20}H_{12}ONBr_3$ requires Br, 43·3%).

4 : 6 : 4′-*Tribromodiphenylamine-2-carboxylic acid*, obtained from the *N*-benzoyl ester in 90% yield, crystallised from alcohol in sulphur-yellow needles, m. p. 222° (Found: Br, 52·05, 52·05. $C_{13}H_8O_2NBr_3$ requires Br, 53·3%).

1 : 3 : 7-*Tribromoacridone*.—A solution of 4 g. of the last-named acid in 80 c.c. of xylene was treated with 2 g. of phosphoryl chloride, dissolved in 20 c.c. of xylene. The whole was boiled for 2 hours. Solid slowly separated. Water and then dilute alkali were added, and the xylene was removed in a current of steam. The liquid was filtered, and the crude *tribromoacridone* dried (3·5 g.). It crystallised from *m*-cresol in minute yellow needles, m. p. above 300° (Found: Br, 54·7. $C_{13}H_6ONBr_3$ requires Br, 55·5%).

N-p-*Methoxyphenylbenzimino*-p-*chloro*-o-*carbomethoxyphenyl ether*,

$$OMe\cdot C_6H_4\cdot N{:}CPh\cdot O\cdot C_6H_3Cl\cdot CO_2Me,$$

from benz-*p*-anisidideiminochloride and methyl 5-chlorosalicylate, crystallised from alcohol in flat needles, m. p. 105—106° (Found: Cl, 8·7. $C_{22}H_{18}O_4NCl$ requires Cl, 9·0%).

Methyl N-*benzoyl-4-chloro-4′-methoxydiphenylamine-2-carboxylate* was obtained by heating the last-named ether at 200—210° for 10 minutes and then pouring the product into one volume of alcohol. On cooling, 7·5 g. of solid separated, and this on recrystallisation from alcohol gave the methyl ester in prisms and cubes, m. p. 164° (Found: Cl, 9·3. $C_{22}H_{18}O_4NCl$ requires Cl, 9·0%). Complete hydrolysis of the ester gave 4-chloro-4′-methoxydiphenylamine-2-carboxylic acid, m. p. 191—192° (Feldman and Kopeliovitsch, *loc. cit.*, give 185—186°).

N-*Benzoyl-4-chloro-4′-methoxydiphenylamine-2-carboxylic acid*, obtained by the partial hydrolysis of the methyl ester, crystallised from benzene, in which it was only moderately soluble, in slender needles, containing half a molecule of benzene of crystallisation, after being air-dried (Found: Cl, 8·3. $C_{21}H_{16}O_4NCl,1/2C_6H_6$ requires Cl, 8·4%). It softened and lost benzene at 120—125°, but gave no sharp m. p. at higher temperatures. The solvent-free acid was obtained from the solvated specimen by dissolution in very dilute alkali solution (the sodium salt is sparingly soluble), precipitation with dilute acid, and dehydration in a high vacuum over phosphoric oxide (Found: Cl, 9·1. $C_{21}H_{16}O_4NCl$ requires Cl, 9·3%).

Action of Heat on the Preceding Acid.—The acid was heated for 15 minutes at 300°. Benzoic acid sublimed. The mixture was extracted with boiling alcohol and the residual 3-*chloro*-7-*methoxyacridone* (yield, almost theoretical) was crystallised from phenol, to which a little alcohol was added before the solvent solidified. The acridone formed thin yellow hexagonal plates melting above 300° (Found: Cl, 13·1. $C_{14}H_{10}O_2NCl$ requires Cl, 13·7%).

N-p-*Chlorophenylbenzimino*-p′-*carbomethoxyphenyl ether* was obtained from benz-*p*-chloroanilideiminochloride and methyl *p*-hydroxybenzoate in 57% yield (pure). It crystallised from methyl alcohol in prisms, m. p. 78—79° (Found: Cl, 9·4. $C_{21}H_{16}O_3NCl$ requires Cl, 9·7%).

Methyl N-*benzoyl-4-chlorodiphenylamine-4′-carboxylate* was obtained by heating the above

ether. With the bath at 277° the temperature of the mixture rose to 290°. The ester crystallised from alcohol in prisms, m. p. 140—141° (Found: Cl, 9·4. $C_{21}H_{16}O_3NCl$ requires Cl, 9·7%). Yield, 90%.

N-*Benzoyl-4-chlorodiphenylamine-4'-carboxylic acid*, obtained in 61% yield by the partial hydrolysis of the methyl-benzoyl ester, crystallised from alcohol in slender needles, m. p. 223—224° (Found: Cl, 10·1. $C_{20}H_{14}O_3NCl$ requires Cl, 10·1%).

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412. *Gallium. Part V.*

By W. Pugh.

The only complex fluorides of gallium so far described are those of the alkali metals. The present paper describes the preparation and properties of complex *gallifluorides* of *manganese, cobalt, nickel, copper, zinc*, and *cadmium*, all of which are of the type $[M(H_2O)_6][GaF_5,H_2O]$. Complexes of *barium* ($Ba_3[GaF_6]_2,H_2O$), *strontium* ($3SrF_2,GaF_3,3H_2O$), *silver* ($Ag_3[GaF_6],10H_2O$), and *thallium* ($Tl_2[GaF_5,H_2O]$) are also described. Although the alkali and alkaline-earth metal complexes are insoluble in water, those of the heavy metals described are soluble and crystallise from aqueous solution.

The author (this vol., p. 1046) has already described some complex fluorides of gallium and the alkali metals, all of which may be represented as compounds of co-ordination number six, *viz.*, $Li_3[GaF_6]$, $Na_3[GaF_6]$, $(NH_4)_3[GaF_6]$, $K_2[GaF_5,H_2O]$, $Rb[GaF_4,2H_2O]$, and $Cs[GaF_4,2H_2O]$. These are the only complex fluorides of gallium so far described.

Other tervalent metals form complexes with the fluorides of bivalent metals and, as a rule, they are of the general type $M''F_2,M'''F_3,7H_2O$, or, more correctly, $M''[M'''F_5,H_2O],6H_2O$. For instance, Weinland and Köppen (*Z. anorg. Chem.*, 1899, **22**, 266) described complex fluorides of tervalent iron and aluminium with nickel, cobalt, zinc, cadmium, and bivalent iron; Petersen (*J. pr. Chem.*, 1889, **40**, 47, 60) described complexes of tervalent vanadium and chromium with nickel and cobalt, and Piccini and Giorgis (*Gazzetta*, 1892, **22**, I, 90) those of vanadium with zinc and cadmium. Gallium is now shown to form similar *complex fluorides* with bivalent *manganese, cobalt, nickel, copper, zinc*, and *cadmium*. It is noteworthy that, although the copper gallifluoride now described is $Cu[GaF_5,H_2O],6H_2O$, which has a bivalent anion, the corresponding copper complexes with iron and aluminium are of the type $[Cu(H_2O)_6]_3[MF_6]_2$, having a tervalent anion (Weinland, Lang, and Fikentscher, *Z. anorg. Chem.*, 1926, **150**, 51), and the complex with chromium is $[Cu(H_2O)_4][CrF_5,H_2O]$ (Higley, *J. Amer. Chem. Soc.*, 1904, **26**, 630).

Barium and strontium also form complexes with gallium fluoride. The *barium* compound, $3BaF_2,2GaF_3,H_2O$ or $Ba_3[GaF_6]_2,H_2O$, is the analogue of the complex barium ferrifluoride described by Nielsen (*Z. anorg. Chem.*, 1936, **227**, 423). The *strontium* complex fluoride, however, is not of this type, but $3SrF_2,GaF_3,3H_2O$, for which the structure $[SrF,H_2O]_3[GaF_6]$ is suggested.

Of the univalent metals silver and thallium, the former gives rise to only a few complex fluorides. Christensen (*J. pr. Chem.*, 1887, **35**, 169) has prepared $AgF,MnF_3,4H_2O$, and Weinland, Lang, and Fikentscher (*loc. cit.*) have recently prepared $[Ag(H_2O)_2][FeF_4,H_2O]$. With gallium fluoride, silver forms the *complex* $Ag_3[GaF_6],10H_2O$. Univalent thallium shows a strong resemblance to the alkali metals and forms similar complexes; *e.g.*, Ephraim and Barteczko (*Z. anorg. Chem.*, 1909, **61**, 238) have described compounds of iron, aluminium, and chromium of the type $Tl_3[MF_6]$, and Weinland, Lang, and Fikentscher (*loc. cit.*) have recently prepared $Tl_2[FeF_5,H_2O],2H_2O$. With gallium fluoride, thallium yields the *analogue* of potassium gallifluoride, *viz.*, $Tl_2[GaF_5,H_2O]$.

Experimental.

Methods of Analysis.—In all the preparations described herein, fluorine was determined by precipitation as lead chlorofluoride, followed by volumetric estimation of chlorine in the precipitate (Hillebrand and Lundell, "Applied Inorganic Analysis," p. 605). For the determination of the metals, fluorine was first removed by evaporation with concentrated sulphuric acid and, when the second metal did not interfere with the method, gallium was precipitated as the tannin complex; when this was not possible, cupferron was used (Moser and Brukl, *Monatsh.*, 1928, **50**, 657; 1929, **51**, 73). For the thallium compound, ammonia was used so that thallium could subsequently be precipitated as chromate.

Manganese Gallifluoride, $[Mn(H_2O)_6][GaF_5,H_2O]$.—For this and all the following preparations hydrated gallium fluoride, $GaF_3,3H_2O$, was used; it was made from pure gallium as already described by the author (*loc. cit.*). All operations were carried out in platinum vessels.

Manganese carbonate contains higher oxides of manganese, which give brown solutions in hydrofluoric acid, and these again give brownish crystals when evaporated with gallium fluoride. The above compound was prepared in the pure state as follows: manganese carbonate (1·5 g.) was dissolved in dilute hydrochloric acid, and the solution evaporated to dryness in order to decompose compounds of ter- and quadri-valent manganese. The residue was dissolved in water and transferred to a platinum basin. Gallium fluoride (2 g.) and dilute hydrofluoric acid were then added, and the solution evaporated to dryness; evaporation with hydrofluoric acid was repeated three times. Finally, the residue was dissolved in 30 c.c. of hot dilute hydrofluoric acid, and the solution allowed to cool. Clear, colourless crystals separated on standing. They were washed with ice-cold water, and dried in the air to constant weight, forming white clusters with a faint pink tinge.

In analysing the *compound*, gallium was precipitated with cupferron, after boiling with sulphur dioxide; and the manganese was determined in the filtrate by the bismuthate method, the excess of cupferron being first destroyed with nitric and sulphuric acids in a Kjeldahl flask (Found: Mn, 15·8; Ga, 20·2; F, 27·2. $[Mn(H_2O)_6][GaF_5,H_2O]$ requires Mn, 15·9; Ga, 20·2; F, 27·5%). When heated at 110°, it loses $5H_2O$ (Found: loss at 110°, 26·1. Calc. for $5H_2O$: 26·0%). It does not lose hydrogen fluoride at this temperature, but during 7 hours at 230° it loses 40% in weight, and the residue contains only 70% of the fluorine in the original substance. It evidently decomposes into manganese fluoride and gallium oxide, and the following five complex salts behave similarly.

The crystals consist of pyramids, which probably belong to the orthorhombic system. In convergent light they show a biaxial negative figure with a very small axial angle (the sign was determined by means of a Berek compensator, and checked with a quartz wedge); *n* 1·45, $D_{20^\circ}^{20^\circ}$ 2·216. The substance is quite stable in air, and very soluble in water.

Cobalt Gallifluoride, $[Co(H_2O)_6][GaF_5,H_2O]$.—Cobalt carbonate (0·64 g.) was dissolved in 30 c.c. of dilute hydrofluoric acid, and gallium fluoride (1 g.) added to the hot solution. Tiny pink crystals appeared immediately. The solution was cooled, and the crystals separated. The mother-liquor was then evaporated slowly in the air to about 2 c.c., whereupon a second crop of crystals, identical with the first, was obtained. The total yield (1·8 g.) was nearly theoretical. The crystals were dried in the air.

Gallium was determined in these crystals by means of cupferron (tannin gave high results, the oxide being contaminated with cobalt oxide) and cobalt was precipitated from the filtrate with hydrogen sulphide and converted into sulphate (Found: Co, 16·8; Ga, 19·9; F, 27·0. $[Co(H_2O)_6][GaF_5,H_2O]$ requires Co, 16·9; Ga, 19·9; F, 27·2%).

The *gallifluoride* forms pale pink crystals, the majority of which appear to be rhombs; prisms terminated by a pyramid also occur. In convergent light they show a biaxial negative figure with a small axial angle, which suggests that they belong to the monoclinic system but have pseudo-hexagonal form; *n* 1·45, $D_{20^\circ}^{20^\circ}$ 2·347. It is quite stable in air, but loses $5H_2O$ at 110°, giving a light mauve mass (Found: loss at 110°, 25·8. Calc. for $5H_2O$: 25·7%). It is only sparingly soluble in water, but dissolves readily in acids with decomposition.

Nickel Gallifluoride, $[Ni(H_2O)_6][GaF_5,H_2O]$.—This was made in exactly the same manner as the cobalt complex from gallium fluoride (1 g.) and an equivalent amount of nickel carbonate, the nickel content of which had been determined. It crystallised readily from 20 c.c. of hot dilute hydrofluoric acid; yield, 1·7 g. Gallium was determined in the air-dried material by precipitation with cupferron; nickel was estimated in the filtrate by dimethylglyoxime (Found: Ni, 16·9; Ga, 19·8; F, 27·4. $[Ni(H_2O)_6][GaF_5,H_2O]$ requires Ni, 16·8; Ga, 19·9; F, 27·2%). *Nickel gallifluoride* forms pale green crystals which appear to be rhombs; in convergent light

they are biaxial negative with a small axial angle, which again suggests the monoclinic system with a pseudo-hexagonal form; n 1·45, $D_{20^\circ}^{20^\circ}$ 2·454. It is stable in air but loses $5H_2O$ at 110° (Found: loss at 110°, 25·7. Calc. for $5H_2O$: 25·8%). The dehydrated material forms yellowish crystals, which turn green again in air. It is only sparingly soluble in water.

Copper Gallifluoride, $[Cu(H_2O)_6][GaF_5,H_2O]$.—Copper oxide (0·66 g.) and gallium fluoride (1·5 g.) were dissolved in 20 c.c. of hot dilute hydrofluoric acid. On cooling, the liquid set to a mass of microscopic crystals. These were redissolved in 50 c.c. of hot dilute hydrofluoric acid, and the solution allowed to evaporate slowly in the air. The pale blue crystalline powder was centrifuged, washed with cold water, and dried in the air; yield, 2·6 g. Copper was determined electrolytically, and gallium was recovered as the tannin complex and weighed as oxide (Found: Cu, 18·0; Ga, 19·8; F, 26·5. $[Cu(H_2O)_6][GaF_5,H_2O]$ requires Cu, 18·0; Ga, 19·7; F, 26·8%). The *gallifluoride* forms a pale blue crystalline powder, but the crystals are too small for accurate characterisation. The forms suggest the monoclinic system; n 1·45, $D_{20^\circ}^{20^\circ}$ 2·202. The salt is sparingly soluble in water, but dissolves, with decomposition, in acids. It is stable in air but loses $5H_2O$ at 110° (Found: loss at 110°, 25·6. Calc. for $5H_2O$: 25·4%).

Zinc Gallifluoride, $[Zn(H_2O)_6][GaF_5,H_2O]$.—This complex salt was made by dissolving molecular proportions of zinc oxide (1·04 g.) and gallium fluoride (2·32 g.) in hydrofluoric acid and evaporating the liquid to a syrupy consistency. The liquid crystallised slowly. The crystals were washed quickly with small quantities of ice-cold water and dried in the air to constant weight. During drying, they smelled strongly of hydrogen fluoride and lost their transparent appearance; it is possible that the freshly crystallised material contains co-ordinated hydrogen fluoride which is replaced by water on standing in air. The cadmium salt behaves in the same way.

In analysing the *substance*, gallium was precipitated by tannin, a double precipitation being necessary, and zinc was recovered as sulphide and converted into sulphate (Found: Zn, 18·3; Ga, 19·7; F, 27·0. $[Zn(H_2O)_6][GaF_5,H_2O]$ requires Zn, 18·4; Ga, 19·6; F, 26·7%). Like the manganese complex, it forms colourless pyramids, which probably belong to the orthorhombic system; in convergent light they show a biaxial negative figure with a small axial angle; n 1·45, $D_{20^\circ}^{20^\circ}$ 2·335. It is very soluble in water. In air it is stable, and even over phosphoric oxide it undergoes no loss in weight in 3 weeks; but it readily loses $5H_2O$ at 110° (Found: loss at 110°, 25·6. Calc. for $5H_2O$: 25·3%. Found, in dehydrated product: Zn, 24·7; Ga, 26·0; F, 35·6. $Zn[GaF_5,H_2O],H_2O$ requires Zn, 24·6; Ga, 26·2; F, 35·7%).

Cadmium Gallifluoride, $[Cd(H_2O)_6][GaF_5,H_2O]$.—This was made from cadmium oxide (2·2 g.) and gallium fluoride (3·1 g.) as for the zinc salt. The concentrated solution on standing gave clear, colourless crystals, which on drying in the air formed a white, crystalline mass. In analysing this substance, cadmium was first separated by double precipitation of the sulphide and gallium was then precipitated with tannin (Found: Cd, 27·9; Ga, 17·2; F, 23·9. $[Cd(H_2O)_6][GaF_5,H_2O]$ requires Cd, 27·8; Ga, 17·3; F, 23·7%). It was not possible to get good crystals for identification, but it is certain that they do not belong to the isometric system; n 1·45, $D_{20^\circ}^{20^\circ}$ 2·778. It is very soluble in water and is stable in air, but loses $5H_2O$ at 110° (Found: loss at 110°, 22·2. Calc. for $5H_2O$: 22·3%).

Barium Gallifluoride, $Ba_3[GaF_6]_2,H_2O$ or $3BaF_2,2GaF_3,H_2O$.—Nielsen (*loc. cit.*) made the corresponding ferric complex by adding freshly prepared barium carbonate to a solution of ferric fluoride. The gallium compound was made by adding, in small quantities at a time, freshly made barium carbonate (from 2 g. of barium chloride) to a solution of gallium fluoride (1 g.) in 100 c.c. of hot dilute hydrofluoric acid. A heavy, white precipitate was formed immediately. The liquid was boiled well, and the solid filtered off, washed, and dried in the air; yield, 2·0 g. (Found: Ba, 51·7; Ga, 17·3; F, 28·5. $Ba_3[GaF_6]_2,H_2O$ requires Ba, 51·7; Ga, 17·5; F, 28·6%). The *gallifluoride* is a sub-microscopic powder, practically insoluble in water; $D_{20^\circ}^{20^\circ}$ 4·063. It loses $\frac{1}{2}H_2O$ at 110°, and the other $\frac{1}{2}H_2O$ at 230°; at a dull red heat it decomposes completely into barium fluoride and gallium oxide.

Strontium Gallifluoride, $3SrF_2,GaF_3,3H_2O$.—This *substance* was obtained as a semi-gelatinous but heavy precipitate by adding strontium carbonate to a hot solution of gallium fluoride in hydrofluoric acid. The same material was produced whether 1, 2, or 3 mols. of strontium carbonate were used per mol. of gallium fluoride. On drying in air, it forms a sub-microscopic powder, almost insoluble in water (Found: Sr, 46·6; Ga, 12·5; F, 30·7. $3SrF_2,GaF_3,3H_2O$ requires Sr, 47·1; Ga, 12·5; F, 30·7%). It loses all its water at 220°, and at a low red heat it decomposes into strontium fluoride and gallium oxide.

Thallous Gallifluoride, $Tl_2[GaF_5,H_2O]$.—Although the corresponding $K_2[GaF_5,H_2O]$ is very sparingly soluble in water, the *thallium* salt is moderately soluble and crystallises well. It was

made by dissolving thallous carbonate (1·57 g.) and gallium fluoride (0·6 g.) in 30 c.c. of dilute hydrofluoric acid, and evaporating the solution to 10 c.c. (Found: Tl, 68·5; Ga, 11·7; F, 16·0. $Tl_2[GaF_5,H_2O]$ requires Tl, 69·1; Ga, 11·8; F, 16·1%). It forms clear transparent prisms and pyramids, which show a biaxial negative figure and appear to belong to the monoclinic or orthorhombic system; *n* 1·645; $D_{20^\circ}^{20^\circ}$ 6·440. It is quite stable in air and also when heated at 110°.

Silver Gallifluoride, $Ag_3[GaF_6],10H_2O$.—This substance is very sensitive to light and all operations had therefore to be carried out in the dark, in which the crystals retain their transparency indefinitely. Moreover, as the substance is exceedingly soluble and difficult to crystallise, considerable difficulty was experienced in making a pure specimen. This was finally accomplished as follows: silver carbonate (7·9 g.), prepared in the dark from pure silver nitrate, was dissolved in 20 c.c. of hydrofluoric acid, and gallium fluoride (3·46 g.) added. The liquid was filtered from the small amount of metallic silver which had separated, and 2 vols. of alcohol were added. The liquid separated into two layers, and the lower, aqueous layer crystallised spontaneously. The crystals were separated, redissolved in 15 c.c. of water, and the liquid was filtered and fractionally precipitated by adding alcohol. The lower layer obtained after adding 2 c.c. of alcohol contained a small excess of gallium fluoride; the upper, alcoholic layer was decanted, and to it were added another 2 c.c. of alcohol and the liquid was covered and left undisturbed. In the course of a few days, large, clear crystals separated from the lower layer. These were extracted, washed with alcohol, and dried in a current of dry air. A further crop of crystals was obtained by adding more alcohol to the remaining liquid (Found: Ag, 46·9; Ga, 10·2; F, 16·7. $Ag_3[GaF_6],10H_2O$ requires Ag, 47·1; Ga, 10·1; F, 16·6%).

Silver gallifluoride forms large clear tabular crystals, biaxial negative and probably monoclinic or orthorhombic; *n* 1·493, $D_{20^\circ}^{20^\circ}$ 2·90. The crystals undergo no change in weight and are not deliquescent, though they have a moist feel. They become anhydrous when kept over phosphoric oxide and also when heated at 110°.

The optical properties described for these substances were determined by Miss M. Cameron Swan, M.A., to whom the author tenders his thanks.

University of Cape Town. [*Received, November 1st*, 1937.]

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413. *The Measurement of Olefin Formation from Certain Alkyl Bromides: The Mechanisms of the Substitution and the Olefin Reactions with Alkyl Halides.*

By William Taylor.

Estimation of the proportion of olefin formed by the reaction of alcoholic sodium ethoxide with five alkyl bromides leads to two main results: (*a*) the proportion of olefin increases on passing from primary through secondary to tertiary bromides—an uncertainty which had existed about the last two is thus removed; and (*b*) two types of olefin mechanism are seen to operate, one in which the ethoxyl ion participates, and the other in which an un-ionised molecule reacts with the alkyl bromide.

Mechanisms for the substitution and the olefin reactions with alkyl halides and either anions or molecular reagents are discussed. In the latter case the mechanisms proposed are based largely on the present work and on that (this vol., pp. 1852, 1853) in which it has been shown that direct action takes place between the alkyl halide and the molecular reagent in both substitution and olefin reactions. These last two mechanisms are alternative to the ionisation mechanisms already proposed by Hughes and Ingold.

The ratio of olefin to substitution reactions, when an alkyl halide reacts with a base such as an alkali-metal hydroxide, alkoxide, or aryloxide, increases with: (i) increase in the strength of the base (see, *e.g.*, Segaller, J., 1913, **103**, 1430) or (ii) in its concentration (see, *e.g.*, Taylor, this vol., p. 343), (iii) rise of temperature (see, *e.g.*, *idem*, *ibid.*), (iv) substitution of tertiary and secondary for primary halides (see, *e.g.*, Brussoff, *Z. physikal. Chem.*, 1900, **34**, 129; Segaller, *loc. cit.*; Hickinbottom, "Reactions of Organic Compounds," 1936, p. 366). Brussoff (*loc. cit.*) found that secondary gave more olefin than tertiary halides,

whereas Segaller (*loc. cit.*) found that the latter gave olefin under conditions such that the former gave none.

Brussoff's method of olefin estimation, adopted also by Segaller, is not capable of high accuracy, and, accurate measurements being required for the elucidation of the mechanisms of the olefin and substitution reactions with alkyl halides, these have now been carried out at 25° and 55° with different proportions of sodium ethoxide in dry ethyl alcohol with the following bromides: primary, ethyl and β-phenylethyl; secondary, *iso*propyl and α-phenylethyl; tertiary, *tert.*-butyl. In addition, the proportions of olefin from the same bromides in the solvents ethyl alcohol, water, and carbon tetrachloride without any added sodium ethoxide, and from the bromides alone without any solvent or base, were, in some instances, also measured at the same temperatures and for the same periods of time as when alcoholic sodium ethoxide was used. The method of olefin estimation consisted of bromine addition in the well-washed carbon tetrachloride extract of the reaction liquid. It was essential to wash out all traces of alcohol from the extract. The results, showing the percentages of olefin formed, are in the table.

Table showing the effect of temperature, structure, solvent, and concentration of sodium ethoxide in alcohol on the percentage of olefin formation. The initial molar concentration of the bromide was always less than that of the base in order to avoid solvent effect, and at the higher concentrations of the base was always approximately 0·2. *The time, in hours, and the same throughout for any one bromide at any one temperature, is recorded in parentheses after the temperature.*

Medium.	Bromide.									
	Et.		Pr^{β}.		Bu^{γ}.		$CH_2Ph{\cdot}CH_2$.		$CH_3{\cdot}CHPh$.	
	25° (504).	55° (70).	25° (528).	55° (120).	25° (24).	55° (2).	25° (90).	55° (3).	25° (48).	55° (5).
Vapour	—	—	1·6	1·8	1·7	1·9	—	—	—	—
CCl_4	0	0	0	0	0	0	0	0	0	0
H_2O	—	—	—	—	1·8	2·3	—	—	—	—
H_2O + EtOH (1 : 1 by vol.)	—	—	3·5	3·6	4·6	4·8	—	—	—	—
EtOH	0	0	9·0	9·0	12·6‖	15·0‖	0	0	3·6	4·1
[NaOEt] = 0·05N. (approx.)	1·0	1·1	20·3	21·4	21·4	28·6	90·5	91·0	8·2	12·0
,, 0·10 ,,	—	—	—	—	33·5	37·4	90·6	91·8	11·1	15·2
,, 0·20 ,,	*	*	25·4§	27·6§	40·1	44·7	91·9†	92·5†	17·5‡	21·2‡
,, 0·40 ,,	—	—	—	—	49·0	53·2	92·2	92·8	21·9	28·3
,, 0·70 ,,	—	—	—	—	61·1	64·6	92·8	93·8	25·0	32·1
,, 1·2 ,,	—	—	—	—	65·0	68·5	93·3	94·4	25·5	32·7
,, 2·7 ,,	1·6	2·3	26·7	29·0	66·1	69·2	93·3	94·1	26·0	33·5

* Taylor (J., 1935, 1515) found 1·3.

† Taylor (this vol., p. 344) found 91·1 and 91·9 ± 1·2 respectively.

‡ Taylor (*ibid.*) found 19·3 and 20·7 ± 0·6 respectively.

§ Hughes, Ingold, and Shapiro (J., 1936, 235) found, with initial [$Pr^{\beta}Br$] ~ 0·1 and [NaOH] ~ 0·85 in "80%" aqueous alcohol at 50°, 56·76% of olefin. A repetition of their method of estimation, however, revealed a distinct possibility of alcohol vapour having passed over into the standard bromine.

‖ Cooper, Hughes, and Ingold (this vol., p. 1280), employing the same method of olefin estimation as that used here, found, for the complete conversion of the bromide, 12·6% olefin in "80%" aqueous ethyl alcohol at 25°. The olefin percentages given here when solvents alone were used are probably rather low for the reason given on p. 1967. They are, however, comparable among themselves.

(*a*) The results clearly show that, under the same conditions, with the series ethyl, *iso*propyl and *tert.*-butyl bromides, the proportion of olefin rises on passing from primary to *sec.*- and then to *tert.*-bromide. This removes any doubt as to the influence of structure on the proportion of olefin formation.

(*b*) Although β-phenylethyl bromide remains almost unchanged during 3 hours at 55° and yields no measurable olefin in dry ethyl alcohol alone, a very low concentration (*i.e.*, 0·05N.) of sodium ethoxide causes its complete reaction during this time and at this temperature, and produces *ca.* 90% of olefin. It is known (see, *e.g.*, Jones and Hughes, J., 1934, 1197) that sodium ethoxide in very dilute ethyl-alcoholic solution is a strong electrolyte, and hence it is probable that at this low concentration the ethoxyl ion is the agent responsible for this high proportion of olefin.

(*c*) As was to be expected (see p. 1962), the effects of increased temperature and of increased concentration of the sodium ethoxide are both to increase the proportion of olefin. The concentration effect is large for *iso*propyl, α-phenylethyl, and especially for *tert.*-butyl bromide, but small for the other two compounds. However, there is apparently an upper limit to the olefin proportion formed at any one temperature from any one bromide as the concentration of the base is increased. This limit is reached at different concentrations for the different bromides and at higher concentrations as one proceeds along the series Me, Pr^{β}, Bu^{γ}. There are two possible interpretations of this effect: (i) that it is due to increased ethoxyl-ion concentration and (ii) that the un-ionised molecule NaOEt is more efficient than the ion in olefin formation (or from the opposite viewpoint is less efficient in ether formation). The first is not probable, since the change in the proportion of olefin formation with *tert.*-butyl bromide on proceeding from ethyl alcohol alone—in which [OEt′] $\sim 1 \times 10^{-9 \cdot 5}$—to a 0·05N-solution of the base could not possibly be thus explained. Hence the second explanation is probably correct, and indeed, certain considerations would make it appear that with *all* except β-phenylethyl bromide the ethoxyl ion plays little or no part in producing olefin. These considerations are that, for these four compounds only, the plot of olefin proportion formed during the same periods of time against concentration of base from zero to 2·7N., which is the approximate limit of solubility, is a smooth curve. This suggests that as the concentration of sodium ethoxide increases, it gradually assumes command over the total reaction at the expense of the less effective hydrogen compound HOEt until this command is complete. Hence the olefin proportion rises from the naturally low HOEt level to the relatively high NaOEt level.

(*d*) The effect of solvents alone in producing olefin from these compounds indicates that, although ethyl alcohol may have considerable effect, that of water is always very small, and that of carbon tetrachloride is nil. This is interpreted as showing that it is the basic nature of the solvent which is effective in producing olefin, since ethyl alcohol is a stronger base than water, whereas carbon tetrachloride has no basic properties.

(*e*) When small amounts—usually 0·2—0·3 g.—of *iso*propyl and *tert.*-butyl bromides were heated alone to 25° or 55° in hermetically sealed tubes of approximately 23 c.c. capacity, a very small proportion of olefin was formed. Since the liquids at 20° contained no olefin (direct test), it must have been formed in the vapour state. Brearley, Kistiakowsky, and Stauffer (*J. Amer. Chem. Soc.*, 1936, **58**, 43) have shown that the thermal decomposition of *tert.*-butyl chloride is a clean gaseous unimolecular decomposition (cf. Maass and Wright, *ibid.*, 1924, **46**, 2664; Maass and Sivertz, *ibid.*, 1925, **47**, 2883; Kharasch and Potts, *ibid.*, 1936, **58**, 57; Kistiakowsky and Stauffer, *ibid.*, 1937, **59**, 165; for discussion of the reverse reactions).

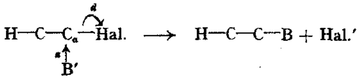
(*f*) Hence, it is seen that in forming olefin from these bromides under these conditions the ethoxyl ion, the un-ionised sodium ethoxide molecule, the solvent alcohol, and even the halide itself are all possible reagents.

Mechanisms of Substitution and Olefin Reactions.

Substitution and olefin reactions (with alkyl halides) of the types discussed above and in preceding papers (this vol., pp. 343, 992) may take place through the agency of anions or of un-ionised molecules.

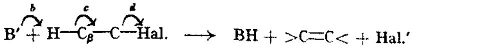
Reactions between Anions and Alkyl Halides.—Where anions only participate, both substitution (see, *e.g.*, Wislicenus, *Annalen*, 1882, **212**, 239) and olefin reactions (see, *e.g.*, Taylor, J., 1935, 1514) are kinetically of the second order and the mechanisms are commonly regarded as being bimolecular, *viz.*,

Substitution reaction (with anion)



(S_a)

Olefin reaction (with anion)

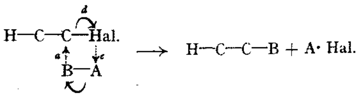


(O$_a$)

One important difference between these two types of reaction is that, although anions which are very feebly basic, *e.g.*, S_2O_3'' or $CH_3\cdot CO\cdot CH_2\cdot CO_2'$, cause the substitution to take place to the practical exclusion of the olefin reaction, the latter occurs the more readily the more strongly basic the anion; *e.g.*, OEt′ (alcoholic potash) is more effective in olefin formation than OH′ (aqueous potash) and both are more effective than the anions mentioned previously. Hence, it follows that, if the strength of a base be defined as its electron-donating power (the opposite viewpoint from proton affinity), then with an increase in this power the electron transfers *b* and *c* are facilitated relatively to *a*. This can only mean that β-hydrogen is more polarisable, *i.e.*, more readily has a positive charge induced on it, than α-carbon, and hence reacts the more readily the more strongly basic the anion. The relative reactivity of either centre will be increased, the more it becomes positively charged relatively to the other. Thus, the presence of a negative β-substituent such as Hal. or Ph confers a positive charge on β-hydrogen, so that, *e.g.*, in β-phenylethyl bromide and ethyl bromide, where the C_α–Hal. link is sensibly the same, olefin is formed in high proportion from the former but scarcely at all from the latter (see table). From the structures suggested by the author (*Rec. trav. chim.*, 1937, **56**, 898) for aliphatic compounds Alk.X, in which there is a supplementary binding of X (in the present case Hal.) by α-hydrogen in all but tertiary compounds, it follows that the positive charge on α-carbon decreases along the series Me, Et, Pr^β, Bu^γ, whereas, for the same halogen, that on β-hydrogen is much the same. Hence, the substitution mechanism will operate with decreasing efficiency in this order (see, *e.g.*, Wislicenus, *loc. cit.*) whilst the tendency to olefin formation will increase (this tendency will not necessarily be effective in producing olefin). The effect of substitution of I for Br or Br for Cl in an alkyl halide, owing to increased polarisability, will be to cause an increased induced positive charge on β-hydrogen relative to α-carbon by the approach of a strongly basic anion and hence increased olefin formation (see also J., 1935, 1514). Thus for the reaction between an alkyl halide and an anion the proportion of olefin formation will be determined by (1) the basic strength of the ion, (2) the relative sizes of the positive charges on α-carbon and β-hydrogen, and (3) the polarisability of the halogen.

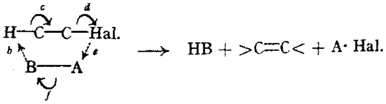
Reactions between Molecules and Alkyl Halides.—When a molecule reacts with an alkyl halide, even when this is tertiary, it has been shown (this vol., p. 1853) that the substitution reaction is kinetically of the second order and the mechanism is here assumed to be bimolecular. It is probable that the corresponding olefin reaction (see above) is similarly bimolecular. In these reactions the molecular reagent is capable of direct attack on all three reactive centres of the alkyl halide, *viz.*, α-carbon, β-hydrogen, and halogen, and the mechanisms proposed are:

Substitution reaction (with molecule)



(S$_m$)

Olefin reaction (with molecule)



(O$_m$)

The various electron shifts are regarded as taking place in small successive stages, and for each stage, simultaneously. In both of the corresponding ionic reactions, since the same

electron transfer *d* must occur before the reaction is completed, it follows that, for any one anion and any one alkyl halide, substitution will be intrinsically preferred since the halogen is the adjoining atom to the α-carbon whilst it is three atoms removed from β-hydrogen. On the other hand, in the molecular mechanisms now proposed there is a direct attack on the halogen in both reactions, and hence, relatively to the ionic reactions, olefin formation will be preferred. This explains why, in the case of, *e.g.*, β-phenylethyl bromide (see table), the proportion of olefin increases with increasing concentration of sodium ethoxide, *i.e.*, with increasing concentration of the un-ionised base. From the above picture of the molecular mechanisms, it is clear that the alkyl halide and the molecule interact mutually, and that the former is as much a reagent as the molecule. Thus when the halogen of the alkyl halide is not partly bound by α-hydrogen (see above), as in *tert.*-butyl bromide, it is more free to react with A of AB, and therefore more readily induces dissociation of AB so that B acquires a greater power of electron donation and becomes a stronger base. Hence olefin formation results at the expense of substitution. It follows that olefin formation with any molecule such as NaOEt or HOEt will increase along the series of bromides Et, Pr^{β}, Bu^{γ}, since the bromine becomes increasingly reactive. This interprets the influence of structure on olefin formation (p. 1963). For a similar reason sodium ethoxide will be more effective than ethyl alcohol for olefin formation, since bromine in any one bromide will stimulate the dissociation of the former more readily than of the latter. Similarly, the alcohol will be more effective for olefin formation than water, since $OH^{\delta-}$ is a weaker base than $OEt^{\delta-}$. This interprets the effect of the constitution of the molecular reagent and of solvents on olefin formation (p. 1964). The ease of dissociation of AB, on which will depend the rate of reaction of the alkyl halide, will be determined, not only by the reactivity of the halogen, but also by the reactivities, *i.e.*, the sizes of the positive charges, of α-carbon and β-hydrogen. This is shown for α-carbon by the relative rates of reaction (mainly substitution) of these bromides with "80%" aqueous ethyl alcohol—Me > Et ~ Pr^{β} ⋘ Bu^{γ} (this vol., p. 992). The positive charge on α-carbon decreases along this series, and the effect of this is apparent from the relative rates of substitution under these conditions with Me and Et: for Pr^{β} and especially for Bu^{γ} this effect is masked by the reactivity of the bromine. The effect of a highly positive and therefore highly reactive β-hydrogen atom on the ease of dissociation of AB is shown by the high proportion of olefin formed when a strongly basic molecule such as NaOEt reacts with a halide in which there is a negative substituent such as Hal. or Ph on the β-carbon atom, *e.g.*, β-phenylethyl bromide. A weakly basic molecule such as HOEt or HOH will not readily be able to react with such a molecule since the bromine is not reactive enough in a primary halide to cause ready dissociation of HOEt. Secondary and especially tertiary halides, only, will have this power. In considering the possible effect of the substitution of I for Br or Br for Cl in an alkyl halide on the proportion of olefin formed by its reaction with a molecular reagent, two factors must be kept in mind: (1) the increased polarisability of halogen which, from what has been stated already, should lead to increased olefin-formation, and (2) the induced reactivities, *i.e.*, positive charges, on β-hydrogen and α-carbon by α-halogen, the ratio of which charges may be taken to decrease the smaller the effect inducing the charges—*i.e.*, decreasing along the series Cl, Br, I—and hence olefin formation will be decreased on this account. The results of Cooper, Hughes, and Ingold (this vol., p. 1280) and of Hughes and MacNulty (*ibid.*, p. 1283), showing that *tert.*-butyl and -amyl chlorides yield higher proportions of olefin than the corresponding bromides and iodides in "80%" aqueous ethyl alcohol at 25°, are here interpreted as being due to the dominant effect of factor (2) when the base, as in this case—a mixture of ethyl alcohol and water—is not readily dissociated. When the molecular base is readily dissociated, as with sodium ethoxide, the effect of factor (1) will be dominant, as ordinary preparative methods of olefins, preferably from the iodides, indicate.

Mechanism (S_m) would interpret the greater accelerating influence of added water on the rates of substitution of alkyl bromides in aqueous alcohol in the order Me, Et, Pr^{β}, Bu^{γ} (this vol., p. 992) as being due mainly to the greater reactivity of bromine in this order. The ionic products of ethyl alcohol and water being approximately 1×10^{-19} and 1×10^{-14}, respectively, it follows that the more reactive the halogen the more readily will water be

dissociated in comparison with alcohol (or conversely, the more readily will the halide be dissociated by water). That α-carbon does exert a slight dissociating influence on the solvent molecules is possibly shown by the very small difference in the above accelerating effect of added water on methyl and ethyl bromides. The acceleration must be also partly ascribed to a true solvent effect (see this vol., p. 1853).

The accelerating effect of an ionic base on reaction rates in aqueous-alcoholic solutions of alkyl halides will, on the above mechanisms, be greatest where the halogen, owing to α-hydrogen bonding, has small reactivity, but β-hydrogen or α-carbon (or both) is highly reactive owing to its being positively charged. The least such effect will occur when the halogen is highly reactive and the positive charge on the α-carbon is negligible as in tertiary halides, for then the high concentration of the solvent, relatively to any *small* ionic concentration of added base, will determine the reaction rate (cf., however, the influence of undissociated base on the proportion of olefin formation—see table). This would explain the decrease in the accelerating effect of an ionic base in the halide series, Me, Et, Pr^{β}, Bu^{γ}.

The failure of acids to accelerate the hydrolysis of alkyl halides must be attributed to the instability of $BrH_2^{\cdot}$ relatively to $OH_3^{\cdot}$, as Bagster and Cooling (J., 1920, **117**, 693) showed by the electrolysis of hydrogen bromide in sulphur dioxide, *i.e.*, $HBr + H_2O \rightarrow H_3O^{\cdot} + Br'$, and *not* $HBr + H_2O \rightarrow H_2Br^{\cdot} + OH'$. This is so, since $AlkBr + OH_3^{\cdot} \rightarrow AlkOH + BrH_2^{\cdot}$ can be supposed to represent the reaction that would occur if acid catalysis could take place.

On the results (this vol., p. 1853) found for the hydrolysis of *tert.*-butyl bromide in acetone, *viz.*, that both this and the reverse reaction are kinetically of the second order and presumably are bimolecular, it is necessary to state that the "complex" in the mechanism (S_m) must be regarded as suffering "instantaneous" decomposition when formed in either direction; *i.e.*, the respective rates must depend on the respective probabilities of the formation of the complex from either pair of reagents. This disposes of the previous suggestion (this vol., p. 344) that the complex might be sufficiently stable to be capable of suffering a unimolecular decomposition.

EXPERIMENTAL.

The bromides were all materials of constant b. p. The requisite amount of the bromide was weighed into 10 c.c. of sodium ethoxide solution in ethyl alcohol dried as described previously (J., 1935, 1520), contained in a tube which was then hermetically sealed. This was protected by a stout closely-fitting outer tube, and placed in a thermostat at the required temperature. When all the bromide had reacted, as was known from kinetic experiments for the higher concentrations of the sodium ethoxide solutions (>0·1N.), the tube was broken in a glass-stoppered bottle containing carbon tetrachloride (30 c.c.), and water (150 c.c.) was then added. The extent of decomposition was checked by titration with standard hydrochloric acid, phenolphthalein being the indicator. With the lower concentrations of sodium ethoxide and for the slower reactions at 25° this method gave the amount of bromide decomposed. When solvents only were used, the same time was allowed to elapse as that taken when alcoholic sodium ethoxide was employed; in these cases no attempt was made to check the extent of decomposition because of the known interaction of hydrogen bromide with ethyl alcohol. For this reason, although these results are comparable amongst themselves, they are not to be relied on as absolute values. The extraction and olefin estimation were carried out by the method previously described (this vol., p. 348), but using carbon tetrachloride (30, 10, 5, and 5 c.c.) washed with much water. In all cases except the styrene estimations, for which conditions already quoted were employed, the bromine addition was performed at room temperatures and during 2 hours.

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414. *Exchange between Light and Heavy Oxygen. Part I. Oxygen Interchange between Sulphate Ions and Water.*

By S. C. DATTA, J. N. E. DAY, and C. K. INGOLD.

By the use of heavy-oxygen water and ordinary sodium sulphate or heavy-oxygen sodium sulphate and ordinary water, it is proved that water and sulphate ions interchange their oxygen, the reaction being catalysed by hydroxide ions. It is suggested that the exchange depends on the partial or complete temporary inclusion of a pair of electrons belonging to a foreign oxygen atom in the central valency shell of the sulphate ion. The main evidence for this idea (from which both the exchange and its characteristic catalysis were predicted) is that the highly nucleophilic hydroxide ion is a much more effective reagent for exchange than the feebly nucleophilic water molecule.

MANY mechanisms are possible by which the anions of oxy-acids might exchange their oxygen with that of solvent water, either in neutral solution, or in the presence of an enhanced concentration of hydroxonium or hydroxide ions. The more apparent possibilities may be divided into three groups:

(1) *Dehydration followed by Hydration.*—We may expect to realise this type of mechanism with anions such as orthosilicate, orthophosphate, or sulphite, since the corresponding acids undergo facile reversible dehydration. It is unnecessary to discuss here whether these dehydrations are intramolecular decompositions of the undissociated acids, proceed by a specialised interaction of the cation and anion, or take any other of the conceivable routes. For the subsequent hydration there are likewise various possibilities which need not separately be considered. We have envisaged the whole group of mechanisms collectively, and may illustrate it by reference to the orthophosphate ion:

$$2PO_4^{---} + 2H^+ \rightleftharpoons 2HPO_4^{--} \rightleftharpoons P_2O_7^{----} + H_2O$$

(2) *Hydration followed by Dehydration.*—Mechanisms of this type become possible with unsaturated ions such as carbonate and nitrate, which, though mesomeric, possess a total unsaturation equivalent to one double bond. Here again there are many possible variations: the water may add either to the acid or to its anion, and may do so either as a molecule, or as a pair of ions, which may attack the unsaturated centre in either order. There are likewise various possible routes for the subsequent dehydration. However, we group all these mechanisms together, and may exemplify them by means of the carbonate ion, employing one canonical structure as a reaction formula in accordance with the usual convention:

$$O_2C{:}O^{--} + H_2O \rightleftharpoons O_2C(OH)_2^{--}$$

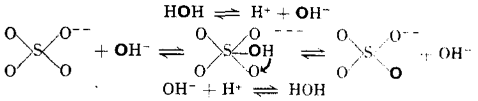
(3) *Temporary Covalency Increase.*—Mechanisms of this type become possible (*a*) when the central atom of the oxy-acid is capable of covalency increase, *e.g.*, when it is 4-covalent and is not a first-row element; (*b*) when an adequate concentration of a sufficiently nucleophilic reagent is provided by the aqueous solvent; and (*c*) when no interference arises through the incursion of mechanisms of types (1) and (2). The sulphate and perchlorate ions might be hoped to satisfy conditions (*a*) and (*c*); whilst, as to (*b*), the water molecule itself is feebly nucleophilic, and the hydroxide ion very strongly so. According to the most elementary conception of this reaction, the nucleophilic reagent would include a pair of its electrons in the valency shell of the central atom of the anion, which, after a proton-migration (Lewis, 1923), would eject a hydroxide ion containing a different oxygen atom. For example, in the hypothetical equation

$$ClO_4^- + OH^- \rightleftharpoons ClO_5H^{--}$$

the chlorine atom temporarily becomes 5-covalent. It may, of course, be suggested that the addition, proton-migration and elimination are less sharply separated in time than this equation implies, and, indeed, one may envisage all the possibilities which lie between a complete separation of the stages and their complete synchronisation; nevertheless, should

it be found that the exchange depends fundamentally on the nucleophilic potency of the reagent, we might justifiably conclude that exchange involves at least partial covalency increase.

Interested especially in the third group of mechanisms, we chose the sulphate ion as the starting point of the present enquiry, since the ability of sulphur to increase its covalency is well established. The technique involved the use of " heavy-oxygen water," *i.e.*, water containing more than the normal proportion of ^{18}O. It is assumed that no appreciable separation of the oxygen isotopes occurs in the course of the experiments, *i.e.*, that " heaviness " conferred on the oxygen of one of the interacting species constitutes a well-fixed label for that particular oxygen. Using heavy type to denote isotopic " heaviness," one possible variant of the reaction we have sought to investigate may be formulated thus :



The forward reaction is between ordinary sulphate ion and heavy water, but naturally one may also study the back-reaction, *i.e.*, that between heavy sulphate ion and ordinary water.

Of the methods available for the preparation of heavy-oxygen water, *viz.*, diffusion (Hertz), distillation (Lewis), and exchange (Urey), the second was used. A relatively simple laboratory still having delivered in quantity water heavier than normal water by 30 p.p.m., we were encouraged to enlist the co-operation of Professor H. E. Watson, who built a much larger and more efficient still, which has already given water heavier than normal water by more than 700 p.p.m. This work will be separately published. The present experiments were carried out with the aid of a sample of water given by the large still in the earlier stages of a distillation. This water had an excess density of 132 p.p.m. Its oxygen was separated by electrolysis and combined with normal hydrogen.* The water thus produced had an excess density of 86 p.p.m., due entirely to the increased proportion of the heavier isotopes of oxygen. The error in a single measurement of density being only 1 p.p.m., the material was quite dense enough for the experiments contemplated.

The materials used were well-dried sodium sulphate and water, and in some experiments an enhanced concentration of hydroxide ions was provided by previously dissolving a small amount of sodium in the water. The neutral or alkaline aqueous solutions of sodium sulphate were heated at 100° for 18—26 hours, after which the water was recovered and examined for changes of density.

The data are contained in the following table. Expts. 1 and 2 show that oxygen exchange between sodium sulphate and neutral water is at most very slow. By contrast, the remaining experiments prove that in the presence of an approximately normal con-

Distribution of Heavy Oxygen between Sulphate Ions and Water.

Expt. No.	Time at 100° (hrs.).	Materials (wt. in g.).	H_2O wt. (g.).	Excess density (p.p.m.). Original H_2O.	Recovered H_2O.	Calc. for equilm.	Density change (p.p.m.). Found.	Calc. for equilm.
1.	18	Na_2SO_4 2·894	6·20	86	86	70	± 0	− 16
2.	26	Na_2SO_4 4·667	9·92	71	68	57	− 3	− 14
3.	22	Na_2SO_4 4·163, Na 0·24	9·15	79	66	64	− 13	− 15
4.	26	Na_2SO_4 4·528, Na 0·25	10·26	71	60	58	− 11	− 13
5.	26	Residue from 4, vacuum-dried at 220°	7·23	0	9	12	+ 9	+ 12

* Actually the hydrogen was " light " by about 2 p.p.m. in terms of water-density.

centration of hydroxide ions rapid interchange of oxygen occurs between the sulphate ion and the solvent water. In expts. 3 and 4 we find that, when the alkaline heavy water is treated with ordinary sodium sulphate, the water undergoes reduction of density to an extent approximately corresponding to a pooling of its oxygen with that of the sulphate. Expt. 5 proves that the "heaviness," which in the previous experiment had disappeared from the water, is really present in the sulphate, since it could be partly recovered therefrom: when this heavy sulphate was treated with alkaline ordinary water the solvent gained in density to an extent once more corresponding approximately to a uniform distribution of oxygen isotopes between the sulphate and the water.

These experiments show that the active agent in the demonstrated exchange of oxygen with the sulphate ion is, not the water molecule, but the hydroxide ion. It will be appreciated that, independently of whether or not the concentration of the hydroxide ions is artificially augmented, the oxygen of the hydroxide ions will at all times be a true sample of the oxygen of the solvent water. This follows from the fact that the hydroxide ion is an ion of water and contains the whole of its oxygen:

$$HOH + OH^- \rightleftharpoons HO^- + HOH$$

The same consideration shows, furthermore, that the hydroxide ion will not merely carry its own oxygen into the exchange reaction with the sulphate ion, but will also act as a vehicle in this sense for the whole of the oxygen of the solvent water. Thus the hydroxide ion could be described as a catalyst for the exchange, but there can be no doubt that the reason why it is a catalyst is because it is the real reagent. The much greater reactivity of the hydroxide ion than of the water molecule in the exchange of oxygen with the sulphate ion is in agreement with our view that this reaction involves a fractional or integral covalency increase of the sulphur atom, and thus depends in an essential manner on the nucleophilic activity of the reagent. A similar mechanism may be suggested to account for the oxygen exchange, very recently reported by Blumenthal and Herbert (*Trans. Faraday Soc.*, 1937, **33**, 849), between the orthophosphate ion and water containing carbonate and hydroxide, but the difficulty of demonstration is greater in this example. Another related observation is that of Anderson (*Z. physikal. Chem.*, 1936, *B*, **32**, 237), who prepared thiosulphate from sulphite and radioactive sulphur, and showed that the latter became free on acidification. Here the isotopic label distinguishes the peripheral from the central sulphur atom of the thiosulphate ion, and we would expect the former to be the more readily eliminated.

Experimental.

Heavy-oxygen Water.—The crude sample from the still (p. 1969) was digested with potassium permanganate and potassium hydroxide for 24 hours at room temperature and then for 32 hours at the b. p. It was distilled from these reagents, redistilled with a little sulphuric acid in order to remove traces of ammonia, and again distilled from potassium hydroxide to remove acid products. It was then given an ordinary distillation at atmospheric pressure, and finally a non-ebullient distillation between 25° and 0° in a sealed, air-free apparatus. Its density at 25° was 132 p.p.m. above that of similarly purified tap-water.

The heavy water was then electrolysed in a divided cell, designed to minimise the usual troubles attending the use of moderate currents, *viz.*, heating, spraying, and mixing of the gases. An outer tube, of 5 cm. internal diameter and 20 cm. long, closed at the bottom, and bearing a small gas-delivery tube at the top, was fitted with a concentric inner tube, of 2·2 cm. internal diameter, and open at its bottom which was about 3 cm. above the bottom of the outer tube. The inner tube also carried a gas-delivery tube near the top, and it contained the anode, an open cylinder of sheet nickel, about 1·5 cm. in diameter and 5 cm. high. The cathode, which was always at earth potential, consisted of a closely wound spiral of copper tubing surrounding the inner glass tube for a height of about 5 cm.* Both electrodes were arranged so that their bottoms were about 2 cm. above the bottom of the inner glass tube. When the cell was being operated a rapid stream of tap-water was passed through the tubular cathode; also the outer glass tube was surrounded with ice-water. With this arrangement a current of 5 amps. could

* The copper tubing had to be first bent double and then wound, in order to get the spiral into the available space with both ends of the tubing projecting from the top of the cell.

be used without appreciable heating of the electrolyte. The gas-space at the top was sufficient for the subsidence of the froth and most of the spray; and the vertical clearance between the electrodes and the bottom of the inner tube was enough to prevent more than a very slight mixing of the gases through the swirling of the electrolyte in the neighbourhood of the electrodes. The evolved oxygen was dried by passage through an empty U-tube cooled by means of solid carbon dioxide. The requisite conductivity was provided by adding 0·8 g. of sodium hydroxide to each 100 c.c. of the water.

The hot copper which was used to catch the oxygen from the cell was prepared in a Pyrex combustion tube by the reduction of copper oxide by means of hydrogen, previously freed from traces of oxygen by passage over red-hot copper in another tube and subsequently dried. When the reduction was complete, *i.e.*, when water ceased to be formed, the excess of hydrogen was swept away by a stream of nitrogen, previously freed from oxygen and moisture in the same manner as the hydrogen. Before being connected to the tube, thus prepared, of hot copper in nitrogen, the electrolytic cell was operated for 10 minutes in order to sweep out any contained air; and, after the connection was made, the stream of nitrogen was continued, primarily in order to prevent the creation of a partial vacuum owing to the absorption of the oxygen, and partly also to reduce the local heating due to the absorption. It was necessary completely to prevent the access of air to the exit end of the tube of hot copper, and with this object an extension of the tube was caused to dip under water, and the nitrogen supply was so regulated that the pressure in the tube was never less than atmospheric. The gases entering the hot tube contained, besides nitrogen and oxygen, a trace of hydrogen arising from the slight mixing of the cell gases; and this hydrogen was, of course, converted into water. Any residual moisture arising in this way was swept out of the tube by continuing the nitrogen stream after the cessation of electrolysis.

After disconnection of the electrolytic cell, the caught oxygen was reconverted into water by means of a stream of hydrogen drawn from a cylinder, and freed from oxygen and moisture by methods similar to those already described. The approximately normal isotopic composition of this hydrogen (p. **1969**, footnote) had previously been established by combining it with the oxygen of electrolysed tap-water, and comparing the density of resultant water with that of the original water. The water from this normal hydrogen and the heavy oxygen, collected at the temperature of ice-water and purified as described for the original water, had, at 25°, a density 86 p.p.m. greater than that of similarly purified tap-water.

Interchange Experiments.—The sodium sulphate was first dried at 225° and atmospheric pressure for 24 hours; it was then heated strongly in a vacuum to constant weight, although the loss of weight in this second stage of drying was found in practice to be negligible.

The reagents, in the quantities given in the table, were enclosed in 50-c.c. bulbs, which were heated in boiling water for the stated times. Each bulb, after being cooled, was opened, and the water was distilled out, the residue being strongly heated. The distillate was then purified as usual, except that sodium was added instead of sodium hydroxide in the distillation to remove acids. The apparatus used for the purification was similar to that described by Day, Hughes, Ingold, and Wilson (J., **1934**, 1598), and the procedure was essentially the same except that no oxygen was passed. All purified samples of water were tested for, and found to be free from, sulphate ion and ammonia.

The determinations of density were made with a 3-c.c. pyknometer as described on p. **1599** of the paper referred to. Individual measurements are believed to be reliable to ±1 p.p.m., and differences to ±2 p.p.m.

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415. *Investigations of the Olefinic Acids. Part XVI. The Synthesis of Δ^{10}-n-Undecenoic Acid.*

By Peter Gaubert, R. P. Linstead, and H. N. Rydon.

Syntheses of Δ^{6}-*n*-heptenoic, Δ^{8}-*n*-nonenoic, and Δ^{10}-*n*-undecenoic acids are described. The last-named product is identical with the material made from castor oil; thus, after sixty years, the constitution of this acid receives synthetic confirmation.

ALTHOUGH Δ^{10}-*n*-undecenoic acid was first obtained sixty years ago by the pyrolytic distillation of castor oil under reduced pressure (Krafft, *Ber.*, 1877, **10**, 2034) and is an intermediate in the perfume industry, no synthetic evidence as to its constitution has been put forward. Its accepted structure rests on the facts that it yields sebacic acid on oxidation (Becker, *Ber.*, 1878, **11**, 1414; Krafft and Seldis, *Ber.*, 1900, **33**, 3572; Chuit and co-workers, *Helv. Chim. Acta*, 1926, **9**, 1074), and *n*-undecoic acid on reduction (Krafft, *Ber.*, 1878, **11**, 2219; Fokin, *Z. angew. Chem.*, 1908, **22**, 1499). The other degradative evidence, *viz.*, the production of acetic and *n*-nonoic acids by alkali-fusion (Becker, *loc. cit.*), is anomalous and recalls the misleading alkali-fusion of oleic acid.

The starting material for our synthesis was Δ^4-*n*-pentenol (I; $n = 3$), which can be obtained in good yield by the action of sodium on the readily accessible tetrahydrofurfuryl chloride (Paul, *Bull. Soc. chim.*, 1935, **2**, 745). The synthesis was carried out by the straightforward but arduous process of repeating the following series of reactions three times, n being successively 3, 5, and 7:

$$\text{(I.)}\quad CH_2{:}CH{\cdot}[CH_2]_n{\cdot}OH \xrightarrow[C_5H_5N]{PBr_3} CH_2{:}CH{\cdot}[CH_2]_n{\cdot}Br \quad \text{(II.)}$$

$$\downarrow CHNa(CO_2Et)_2$$

$$\text{(IV.)}\quad CH_2{:}CH{\cdot}[CH_2]_n{\cdot}CH(CO_2H)_2 \xleftarrow{\text{hydrolysis}} CH_2{:}CH{\cdot}[CH_2]_n{\cdot}CH(CO_2Et)_2 \quad \text{(III.)}$$

$$\downarrow -CO_2$$

$$\text{(V.)}\quad CH_2{:}CH{\cdot}[CH_2]_n{\cdot}CH_2{\cdot}CO_2H \xrightarrow[\text{of ester}]{\text{reduction}} CH_2{:}CH{\cdot}[CH_2]_n{\cdot}CH_2{\cdot}CH_2{\cdot}OH$$

Δ^6-*n*-Heptenoic acid (V; $n = 3$), obtained from the first series of reactions, had previously been prepared by Wallach (*Annalen*, 1900, **312**, 207) by the action of nitrous acid on 7-amino-*n*-heptoic acid, and by Fairweather (*Proc. Roy. Soc. Edin.*, 1926, **46**, 71) as a by-product in the electrolysis of the half-ester of suberic acid; the latter method did not appear suitable for the preparation of large quantities of material, and the purity of the product prepared by Wallach's method was uncertain (cf. Linstead and Rydon, J., 1934, 1996). The structure of our synthetic acid was proved by oxidation to adipic acid.

The second series of reactions, starting with Δ^6-n-*heptenol* (I; $n = 5$), obtained by reduction of ethyl Δ^6-*n*-heptenoate, yielded Δ^8-*n*-nonenoic acid (V; $n = 5$). This acid had previously also been prepared by an electrolytic method (Franke and Liebermann, *Monatsh.*, 1922, **43**, 4596; cf. Crum Brown and Walker, *Annalen*, 1893, **274**, 61). The structure of our material was confirmed by oxidation, by means of potassium permanganate in sodium bicarbonate solution, to suberic acid. A similar oxidation in potassium hydroxide solution gave a product containing much pimelic acid; this is another example of the type of abnormal oxidation discovered by Lapworth and Mottram (J., 1925, **127**, 1987; cf. Green and Hilditch, this vol., p. 764).

The third series of operations starting with Δ^8-*n*-nonenol (I; $n = 7$), prepared from ethyl Δ^8-*n*-nonenoate, yielded Δ^{10}-*n*-undecenoic acid (V; $n = 7$). The recrystallised synthetic material melted at 24—24·5°; a mixture of this with a purified specimen of the product from castor oil, m. p. 24·5—25° (for which we are much indebted to Dr. J. C. Smith), melted at 24—25°.

EXPERIMENTAL.

Δ^6-n-*Heptenoic Acid*.—The following is an improvement of the earlier methods for the preparation of Δ^4-*n*-pentenol (Paul, *loc. cit.*; *Bull. Soc. chim.*, 1933, **53**, 424; Robinson and L. H. Smith, J., 1936, 196). A mixture of 290 g. of tetrahydrofurfuryl chloride (Kirner, *J. Amer. Chem. Soc.*, 1930, **52**, 3251) and 300 c.c. of dry ether was added in drops during 5 hours to a stirred suspension of "molecular" sodium in 500 c.c. of dry ether. After refluxing for a further hour, much of the ether was distilled off and the residue was cautiously decomposed with ice. The ethereal layer was separated, dried over potassium carbonate, and distilled. The yield of Δ^4-*n*-pentenol, b. p. 134—137°/751 mm., was 82%.

A mixture of 200 g. of the pentenol and 50 g. of dry pyridine was added in drops during 5 hours to 252 g. of phosphorus tribromide, mechanically stirred and cooled in ice. The product was distilled (glycerol bath) with continued stirring until thick white fumes appeared.

The distillate was washed with 10% sodium hydroxide solution and water, dried and distilled, yielding 230 g. (67%) of Δ^4-*n*-pentenyl bromide (II; *n* = 3), b. p. 125—129°.

365 G. of the pentenyl bromide were cautiously added to ethyl sodiomalonate prepared from sodium (57 g.), absolute alcohol (570 g.), and ethyl malonate (480 g.). After refluxing overnight, the product was poured into calcium chloride solution and extracted with ether. Distillation of the dried extract yielded 415 g. (74%) of ethyl Δ^4-*n*-pentenylmalonate, b. p. 130—136°/14 mm. A similar experiment with pentenyl chloride (Paul, *Ann. Chim.*, 1932, 18, 337) in place of the bromide gave only a 46% yield. 257 G. of the pentenylmalonic ester were hydrolysed overnight with a solution of 350 g. of potassium hydroxide in 400 c.c. of water and 50 c.c. of alcohol. The solution was concentrated in a vacuum, acidified, and thoroughly extracted with ether. Evaporation of the dried extract left an oil, which rapidly solidified in a vacuum desiccator; yield, 182 g. (94%). Crystallisation from benzene–light petroleum (b. p. 60—80°) yielded Δ^4-n-*pentenylmalonic acid* (IV; *n* = 3), m. p. 87° (Found: C, 55·6; H, 6·9. $C_8H_{12}O_4$ requires C, 55·8; H, 7·0%).

30 G. of the pentenylmalonic acid were decarboxylated at 150° for 24 hours. The cooled product was treated with an excess of aqueous sodium bicarbonate, and neutral by-products removed with ether; the residual solution was acidified and extracted with ether. Two distillations of the dried extract afforded 15 g. (67%) of Δ^6-*n*-heptenoic acid (V; *n* = 3), b. p. 125°/15 mm., m. p. − 6·5°, $n_D^{14\cdot9^\circ}$ 1·4404, $d_{4^\circ}^{14\cdot9^\circ}$ 0·9515, $[R_L]_D$ 35·50 (calc., 35·60) (Found: C, 66·1; H, 9·6; equiv., 129. Calc.: C, 65·6; H, 9·4%; equiv., 128). The p-*toluidide* had m. p. 59·6° after crystallisation from light petroleum (b. p. 40—60°) (Found: C, 77·8; H, 8·9. $C_{14}H_{19}ON$ requires C, 77·4; H, 8·7%).

To an ice-cooled, stirred solution of 3 g. of the acid in aqueous sodium bicarbonate, an excess of 3% potassium permanganate solution was added during 3 hours. After standing overnight, the product was decolourised with sulphur dioxide and thoroughly extracted with ether. Evaporation of the dried extract left a solid; crystallisation from benzene–light petroleum (b. p. 60—80°) yielded 2 g. of adipic acid, m. p. and mixed m. p. 150°.

Δ^8-n-*Nonenoic Acid.*—206 G. of Δ^6-*n*-heptenoic acid were treated with 250 c.c. of thionyl chloride, and the reaction completed by warming on the water-bath for an hour; distillation yielded 220 g. (93%) of Δ^6-*n*-heptenoyl chloride, b. p. 70°/20 mm. 33 G. of this were treated with 30 c.c. of absolute alcohol; after a week the mixture was poured into calcium chloride solution and extracted with ether, and the extract washed, first with sodium bicarbonate solution and then with water. Distillation of the dried extract yielded 33 g. (94%) of ethyl Δ^6-*n*-heptenoate, b. p. 89—91°/22 mm. (Found: C, 69·2; H, 10·3. Calc.: C, 69·2; H, 10·2%). When the mixture was refluxed overnight instead of being kept for a week, the yield was only 67%, much high-boiling material being formed.

A solution of 200 g. of ethyl heptenoate in 1000 c.c. of absolute alcohol was run, as rapidly as possible, on 300 g. of clean sodium contained in a 3 l. 3-necked flask fitted with dropping-funnel, mechanical stirrer, and reflux condenser. After the addition the mixture was heated to 140° and stirred overnight. The product was cooled to 100°, and a further 500 c.c. of alcohol were added; the condenser was then reversed and the heating continued, while water was added from the dropping-funnel, until the distillate was no longer unsaturated. Ethyl alcohol was removed from the first 1500 c.c. of distillate by distillation through a long column. The residue was added to the last runnings from the distillation, and the whole saturated with potassium carbonate and extracted with ether. The product was dried over potassium carbonate and yielded 105 g. (72%) of Δ^6-n-*heptenol* (I; *n* = 5), b. p. 105°/20 mm., $n_D^{20^\circ}$ 1·4403, $d_{4^\circ}^{20^\circ}$ 0·8455, $[R_L]_D$ 35·76 (calc., 35·58) (Found: C, 73·0; H, 12·4. $C_7H_{14}O$ requires C, 73·7; H, 12·3%).

A mixture of 105 g. of the heptenol and 20 g. of pyridine was added dropwise, with ice-cooling and stirring, to 100 g. of phosphorus tribromide during 4 hours. The product was distilled under 10 mm. to a bath temperature of 145°. The distillate was washed thrice with 10% sodium hydroxide solution, twice with water, dried, and re-distilled, affording 94 g. (58%) of Δ^6-n-*heptenyl bromide* (II; *n* = 5), b. p. 77—81°/20 mm., which appeared to contain a little dibromoheptane (Found: Br, 46·2. $C_7H_{13}Br$ requires Br, 45·2%).

The condensation of the heptenyl bromide (92 g.) with the sodio-compound of ethyl malonate (95 g.) was carried out as in the case of the pentenyl bromide. Yield of ethyl Δ^6-*n*-heptenylmalonate (III; *n* = 5) 115 g. (86%), b. p. 138—144°/2 mm. This was hydrolysed overnight with a solution of 150 g. of potassium hydroxide in 200 c.c. of water and a little alcohol. The solution was concentrated under reduced pressure and then acidified. The precipitated acid was removed, and the filtrate extracted with ether; the solid obtained by evaporation of the dried extract was added to the rest of the acid, and the whole crystallised from benzene–light

petroleum (b. p. 60—80°), yielding 78 g. (87%) of Δ⁶-n-*heptenylmalonic acid* (IV; $n = 5$), m. p. 90—91° [Found : C, 60·0; H, 8·0; equiv., 99·8. $C_{10}H_{16}O_4$ (dibasic) requires C, 60·0; H, 8·0%; equiv., 100].

40 G. of pure heptenylmalonic acid after 4 hours' heating at 140° yielded 26 g. (83%) of Δ⁸-n-*nonenoic* acid (V; $n = 5$), b. p. 116—118°/1 mm., m. p. 5°, $n_D^{15°}$ 1·4492, $d_{4°}^{15·8°}$ 0·9146, $[R_L]_D$ 45·77 (calc., 44·83) [Found : C, 68·9; H, 10·3; equiv. (by titration), 155·6. $C_9H_{16}O_2$ requires C, 69·2; H, 10·2%; equiv., 156·0]. This acid has a not unpleasant waxy odour, markedly different from the unpleasant rancid odour of its lower homologues. The p-*toluidide* had m. p. 68° after crystallisation from light petroleum (b. p. 60—80°) (Found : C, 78·0; H, 9·8. $C_{16}H_{23}ON$ requires C, 78·4; H, 9·4%).

Oxidation of 4 g. of the acid with potassium permanganate in sodium bicarbonate solution as before gave 3·2 g. of suberic acid, m. p. 135°, mixed m. p. 135—136°. 2 G. of the acid were similarly oxidised, 10% sodium hydroxide solution being used in place of the bicarbonate; the product (1·7 g.) had m. p. 78—82° and was shown by analysis to be a mixture of pimelic and suberic acids (Found : C, 53·9; H, 7·7; equiv., 84. Calc. for pimelic acid : C, 52·5; H, 7·5%; equiv., 80. Calc. for suberic acid : C, 55·1; H, 8·0%; equiv., 87).

25 G. of the nonenoic acid were treated with 25 c.c. of thionyl chloride, the reaction being completed on the water-bath. Distillation of the product yielded 24 g. (86%) of Δ⁸-*n*-nonenoyl chloride, b. p. 110°/30 mm. This was added cautiously to 25 c.c. of absolute alcohol; the mixture was kept at room temperature overnight and then heated on the water-bath for an hour. Ethyl Δ⁸-*n*-nonenoate (23 g.; 81%) had b. p. 114—116°/15 mm.

A solution of 23 g. of the ester in 100 c.c. of absolute alcohol was run rapidly on 30 g. of clean sodium under reflux. The product was heated at 140° for 4 hours with mechanical stirring, 100 c.c. of rectified spirit were then run in, followed by 100 c.c. of water, and the Δ⁸-n-*nonenol* (I; $n = 7$) was isolated by the procedure described above for Δ⁶-*n*-heptenol. Yield, 9 g. (51%), b. p. 135°/20 mm., $n_D^{23°}$ 1·4450, $d_{4°}^{23°}$ 0·8394, $[R_L]_D$ 45·02 (calc., 44·60) (Found : C, 75·6; H, 12·9. $C_9H_{18}O$ requires C, 76·0; H, 12·7%).

A mixture of 9 g. of the nonenol and 1·5 g. of pyridine was added dropwise during 30 minutes to 7 g. of phosphorus tribromide with stirring and ice-cooling. Stirring was continued for 4 hours and the product was then distilled under reduced pressure. The distillate was taken up in ether, washed with dilute sodium hydroxide solution, dried, and redistilled, yielding 8 g. of Δ⁸-n-*nonenyl bromide* (II; $n = 7$), b. p. 110—115°/15 mm. (Found : Br, 38·8. $C_9H_{17}Br$ requires Br, 39·0%). The bromide was condensed with ethyl sodiomalonate (from 10·5 g. of ester) to give 9 g. (81%) of ethyl Δ⁸-*n*-nonenylmalonate (III; $n = 7$), b. p. 136°/1 mm. On hydrolysis as before, a solid acid was obtained, which was dried on a porous tile and recrystallised from benzene–petroleum (b. p. 80—100°). Δ⁸-n-*Nonenylmalonic acid* (IV; $n = 7$) had m. p. 107° (Found : C, 62·5; H, 9·1. $C_{12}H_{20}O_4$ requires C, 63·2; H, 8·8%).

Δ¹⁰-n-*Undecenoic Acid*.—8 G. of the nonenylmalonic acid were heated at 140° for 3 hours. The residue, which solidified on cooling, was taken up in sodium bicarbonate solution and freed from neutral matter by ether extraction. The residual solution was acidified and extracted with ether. Distillation of the dried extract yielded 3·4 g. (53%) of Δ¹⁰-*n*-undecenoic acid (V; $n = 7$), b. p. 131°/1 mm., m. p. 22—23°. This crystallised from *n*-hexane at − 18° in shining leaflets, m. p. 24—24·5° (compare Ashton and Smith, *loc. cit.*).

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416. *Investigations of the Olefinic Acids. Part XVII. The Addition of Hydrogen Bromide to Heptenoic and Nonenoic Acids with Terminal Double Bonds.*

By PETER GAUBERT, R. P. LINSTEAD, and H. N. RYDON.

The addition of hydrogen bromide to Δ⁶-*n*-heptenoic and Δ⁸-*n*-nonenoic acids has been studied with reference to the effect of solvents and peroxides. The results are reviewed in the light of other work in this field.

THE addition of hydrogen bromide to the heptenoic and nonenoic acids (preceding paper) was studied under various conditions. We also re-examined the behaviour of allylacetic acid in view of a discrepancy between our previous results (Linstead and Rydon, J., 1934,

2001) and those of Kharasch and McNab (*Chem. and Ind.*, 1935, **54**, 989). Stated briefly, the American investigators (who used a different technique) had confirmed our observation that terminal additions of bromine occurred in the presence of peroxide, but obtained γ-bromovaleric acid in the presence of anti-oxidants, whereas we obtained terminal addition in hexane even in the presence of hydrogen or anti-oxidants.*

A repetition of our experiments in peroxide-free hexane with hydrogen bromide prepared catalytically from its elements has now confirmed our previous result that terminal addition occurred in the presence of both hydrogen and diphenylamine. This interesting anomaly is discussed later.

In the case of the higher acids, the direction of addition was determined, where possible, by direct comparison of the hydrobromide with material independently synthesised. For this purpose, 7-bromo-*n*-heptoic acid (IV) was prepared by the following method, the last stage of which follows the method of von Braun (*Ber.*, 1906, **39**, 4362):

$$\mathrm{Br{\cdot}[CH_2]_5{\cdot}Br \longrightarrow \underset{(I.)}{PhO{\cdot}[CH_2]_5{\cdot}Br} \longrightarrow PhO{\cdot}[CH_2]_5{\cdot}CH(CO_2Et)_2\ (II.) \longrightarrow}$$
$$\mathrm{(III.)\ PhO{\cdot}[CH_2]_6{\cdot}CO_2H \longrightarrow Br{\cdot}[CH_2]_6{\cdot}CO_2H\ (IV.)}$$

When such direct comparison was not possible, the bromo-acid was converted into the corresponding dibasic acid by esterification, condensation with ethyl sodiomalonate, and acid hydrolysis:

$$\mathrm{CHRBr{\cdot}[CH_2]_n{\cdot}CO_2H \longrightarrow CHRBr{\cdot}[CH_2]_n{\cdot}CO_2Et \longrightarrow}$$
$$\mathrm{(CO_2Et)_2CH{\cdot}CHR{\cdot}[CH_2]_n{\cdot}CO_2Et \longrightarrow CO_2H{\cdot}CH_2{\cdot}CHR{\cdot}[CH_2]_n{\cdot}CO_2H}$$

β-*Methylsuberic acid* (VIII), required for reference, was prepared synthetically from δ-acetovaleric ester (V) by the following series of reactions:

$$\mathrm{(V.)\ Me{\cdot}CO{\cdot}[CH_2]_4{\cdot}CO_2Et \xrightarrow{CH_2Br{\cdot}CO_2Et,\ Zn} CO_2Et{\cdot}CH_2{\cdot}\overbrace{CMe{\cdot}[CH_2]_4{\cdot}CO}^{O}\ (VI.) \longrightarrow}$$
$$\mathrm{(VII.)\ CO_2Et{\cdot}CH{:}CMe{\cdot}[CH_2]_4{\cdot}CO_2Et \longrightarrow CO_2H{\cdot}CH_2{\cdot}CHMe{\cdot}[CH_2]_4{\cdot}CO_2H\ (VIII.)}$$

Our attempt to synthesise β-methylsebacic acid from 8-ketononoic acid by a similar process failed, but it confirmed some similar experiments by Barger, Robinson, and L. H. Smith (this vol., p. 718), an account of which appeared after the completion of our results. We obtained 8-ketononoic acid, identical with theirs, by the condensation of sodioacetoacetic ester with ethyl 6-bromohexoate. The bromo-ester was prepared, unlike that of Barger, Robinson, and L. H. Smith, by esterifying the product of the addition in petroleum solution of hydrogen bromide to Δ^5-*n*-hexenoic acid (cf. Linstead and Rydon, J., 1934, 1995). This is another example of the formation of a terminal bromo-acid under these conditions.

The results of the additions are summarised below:

Addition of hydrogen bromide to $\mathrm{CH_2{:}CH{\cdot}[CH_2]_n{\cdot}CO_2H}$.

n.	Solvent for acid.	Diluent for HBr.	Catalyst.	Direction of addition.
4	None	Hydrogen	None	Mainly proximate
,,	Acetic acid	,,	,,	,, ,,
,,	Hexane	,,	,,	Terminal
,,	,,	,,	Diphenylamine	Mainly terminal
,,	None	Oxygen	Benzoyl peroxide	,, ,,
6	None	Hydrogen	None	Mainly proximate
,,	Acetic acid	,,	,,	Mixed
,,	Hexane	,,	,,	Mainly terminal
,,	,,	,,	Diphenylamine	,, ,,
,,	None	Oxygen	Benzoyl peroxide	Terminal

Additions were fast in the presence of benzoyl peroxide, slow in the presence of diphenylamine, and intermediate in the other experiments.

* J. C. Smith (*Chem. and Ind.*, 1937, **56**, 833, footnote) reports that addition in hydrocarbon solvents yielded the δ-bromo-acid in the presence of air, but in hydrogen gave an oil which readily lost hydrogen bromide. The γ-isomeride is certainly the less stable of the bromo-acids, but as it can easily be obtained as a crystalline solid from suitable additions (Boorman, Linstead, and Rydon, J., 1933, 575), it seems probable that this product was a mixture.

These results are in general agreement with those obtained in our study of allylacetic acid, but are less clear-cut, possibly because the reactions were slower. They also agree in many respects with Ashton and Smith's observations on undecenoic acid (J., 1934, 435; Smith, *loc. cit.*). The persistent anomaly is the formation of the terminal bromo-acids in hexane or petroleum solution in the presence of hydrogen and anti-oxidant, which we have now observed in the case of five acids of the general formula $CH_2{:}CH{\cdot}[CH_2]_n{\cdot}CO_2H$ (where $n = 1, 2, 3, 4$ and 6), but which is not shown by undecenoic acid ($n = 8$), or by allylacetic acid in the experiments of Kharasch and McNab. This discrepancy may arise from some difference in technique or in the purity of materials, or perhaps in the varying capacity of acids (or of different samples of the same acid) to form a peroxide or similar catalyst.

In spite of the obvious importance of the effect of peroxide or oxygen in determining the orientation of additions of hydrogen bromide generally, we do not consider that the evidence at present available justifies the contention that solvents only influence orientation in so far as they prevent (or enhance) this effect. To take two examples: (i) Sherrill, Mayer, and Walker's experiments on additions to olefins show a profound influence of solvents in the absence of peroxide or oxygen (*J. Amer. Chem. Soc.*, 1934, **56**, 926, 1645). (ii) Vinylacetic acid yields β-bromobutyric acid in the absence of solvent or when dissolved in ether or acetic acid; in the presence of peroxide the β-bromo-acid is still produced, but the γ-bromo-acid is readily and completely formed in hexane even in the presence of hydrogen or anti-oxidants. In view of these facts the statement of J. C. Smith (*loc. cit.*) that the usual orientation of addition is reversed in presence of peroxide is unacceptable, as there is no direct evidence that peroxide has any influence at all in this case. It would be preferable to say that the usual orientation is reversed in hexane solution.

In spite of the uncertainty still attaching to the theoretical position, for practical purposes sufficient information has now been obtained to enable additions to be carried out at will in one or other of the two directions. Thus a terminal bromo-acid will be obtained when hydrogen bromide is passed into a solution of a terminally unsaturated acid in a hydrocarbon in the presence of oxygen or a peroxide. Non-terminal addition will predominate when the acid is undiluted and the reaction is carried out in hydrogen or in the presence of an anti-oxidant.

EXPERIMENTAL.

Synthesis of 7-*Bromo*-n-*heptoic Acid*.—A solution of 10 g. of sodium hydroxide in 30 c.c. of water was added dropwise during an hour, with stirring, to a boiling mixture of 75 g. of pentamethylene dibromide, 24·6 g. of phenol, and 130 c.c. of water. Stirring and refluxing were continued for 5 hours. After cooling, the lower layer was run off, dried, and distilled, yielding 23 g. (29%) of *5-phenoxy-n-amyl bromide* (I), b. p. 160—165°/11 mm. (Found: Br, 32·4. $C_{11}H_{15}OBr$ requires Br, 32·9%). Much pentamethylene dibromide was recovered and used in further experiments.

To a solution of sodium ethoxide prepared from 3·23 g. of sodium in 40 c.c. of absolute alcohol, 22·5 g. of ethyl malonate were added, followed by 34 g. of the phenoxyamyl bromide. The mixture was refluxed on the steam-bath overnight, and the product worked up in the usual manner, yielding 24 g. (53%) of ethyl 5-phenoxy-*n*-amylmalonate (II), b. p. 200—204°/4 mm. 22 G. of this ester were refluxed for an hour with 15 g. of potassium hydroxide, 20 c.c. of water, and 5 c.c. of ethyl alcohol. The alcohol was removed by means of the pump, and the cooled residue acidified. Filtration, followed by drying on a porous tile, gave 15 g. (83%) of 5-phenoxy-*n*-amylmalonic acid, m. p. 116—119°, which on decarboxylation at 150° for 3 hours and crystallisation of the product from light petroleum yielded 9 g. (72%) of 7-phenoxy-*n*-heptoic acid (III), m. p. 55° (Found: C, 69·7; H, 8·0. Calc.: C, 70·3; H, 8·1%) (von Braun, *loc. cit.*, gives m. p. 56—57°).

6 G. of the phenoxyheptoic acid were refluxed for 20 hours with 30 c.c. of hydrobromic acid (*d* 1·48); the product was slowly distilled through a long column until the temperature at the head rose to 120°. The residue was diluted with water and extracted with ether. Distillation of the dried extract yielded 1·5 g. (30%) of 7-bromo-*n*-heptoic acid (IV), b. p. 146—148°/4 mm., which solidified on cooling; m. p. 29° (Found: Br, 37·7. Calc.: Br, 38·3%) (von Braun, *loc. cit.*, gives m. p. 30—31°).

Synthesis of β-Methylsuberic Acid.—55·6 G. of γ-bromobutyric acid (m. p. 29°; prepared by adding hydrogen bromide to vinylacetic acid in hexane solution; Boorman, Linstead, and Rydon, *loc. cit.*) were treated with an ice-cold mixture of 30·6 c.c. of absolute alcohol and 8·1 c.c. of concentrated sulphuric acid. After standing at 0° for 4 hours and at room temperature for 2 days, the product was poured on ice, and the ester isolated in the usual way; yield 50 g. (77%), b. p. 98—100°/20 mm.

17·3 G. of ethyl acetoacetate were added to sodium ethoxide prepared from 3 g. of sodium and 36 c.c. of absolute alcohol. The mixture was treated with 26 g. of ethyl γ-bromobutyrate and refluxed on the steam-bath for 24 hours. On being worked up in the usual way, 21 g. (65%) of ethyl α-acetyladipate, b. p. 165—180°/15—20 mm., were obtained. This was refluxed for 20 hours with 5 vols. of constant-boiling hydrochloric acid; distillation of the product yielded 10 g. (81%) of δ-acetyl-*n*-valeric acid, b. p. 158°/4 mm., m. p. 31—32°. Attempts to reduce this to 6-heptolactone were unsuccessful.

29 G. of acetylvaleric acid were refluxed on the steam-bath for 48 hours with a solution of 1·5 g. of anhydrous hydrogen chloride in 100 c.c. of absolute alcohol, and yielded 28 g. (81%) of ethyl δ-acetyl-*n*-valerate (V), b. p. 132—138°/16 mm. This was refluxed overnight with 27 g. of ethyl bromoacetate and 15 g. of zinc in 500 c.c. of dry benzene. The product was cooled and poured into dilute hydrochloric acid. Extraction with ether, followed by drying and distillation, gave 12 g. of a product, b. p. 120—125°/1 mm., which is considered to be mainly the *lactonic* ester (VI) (Found: C, 62·3; H, 8·5. $C_{11}H_{18}O_4$ requires C, 61·7; H, 8·4%). It was dissolved in 15 c.c. of absolute alcohol and saturated with hydrogen bromide. After standing overnight, the alcohol was removed under reduced pressure, and the residue treated with water; extraction with ether, followed by drying and distillation, afforded 4 g. of partly unsaturated material, b. p. 149—152°/1 mm. This was mixed with 1·2 g. of pyridine and 5 c.c. of benzene and cooled in ice while 2·5 g. of thionyl chloride were added with stirring. After standing overnight, the product was poured into water and extracted with ether; distillation of the dried extract yielded 1·6 g. of an ester, mainly *ethyl 2-methyl-*Δ^1*-n-hexene-1 : 6-dicarboxylate* (VII), b. p. 160—162°/10 mm. (Found: C, 65·0; H, 9·7. $C_{13}H_{22}O_4$ requires C, 64·4; H, 9·1%).

Sulphur compounds were removed by subjecting the unsaturated ester, dissolved in moist ether (100 c.c.), to the action of aluminium amalgam (from 1·5 g. of aluminium foil) for 2 days. The ester recovered from the ethereal filtrate was dissolved in 30 c.c. of glacial acetic acid and shaken in hydrogen with 0·1 g. of Adams's catalyst; the calculated amount of hydrogen for one double bond was taken up in 30 minutes, after which absorption ceased. Distillation of the filtered product gave 0·9 g. of ethyl β-methylsuberate, b. p. 120—125°/5 mm. This was refluxed for 20 hours with 10 c.c. of constant-boiling hydrochloric acid; crystals were deposited on cooling, and a further crop was obtained on concentration of the mother-liquor. Crystallisation from benzene–light petroleum (b. p. 60—80°) gave 0·5 g. of *β-methylsuberic acid* (VIII), m. p. 83° [Found: C, 57·4; H, 8·9; equiv., 92·8. $C_9H_{16}O_4$ (dibasic) requires C, 57·4; H, 8·5%; equiv., 94·0].

Attempted Synthesis of β-Methylsebacic Acid.—The compounds mentioned in this section have all recently been described by Barger, Robinson, and L. H. Smith (*loc. cit.*) and we therefore only give details of those experiments which differ from theirs.

Dry hydrogen bromide was passed into 53 g. of Δ^5-*n*-hexenoic acid (Linstead and Rydon, J., 1934, 1995), dissolved in 300 c.c. of light petroleum (b. p. 60—80°), until the product was saturated. The bromo-acid (90 g.), obtained on removal of the solvent, was cooled in ice and treated with a cold mixture of 7·7 c.c. of concentrated sulphuric acid and 61 c.c. of absolute alcohol. After standing in ice for 4 hours and at room temperature for 2 days, the mixture was poured into water and worked up in the usual way. The product (85 g.), b. p. 126—130°/18 mm., was shown to be ethyl 6-bromo-*n*-hexoate by malonation: 2 G. were added to ethyl sodiomalonate, prepared from 0·2 g. of "molecular" sodium and 1·6 g. of ethyl malonate in benzene, and the mixture heated on the steam-bath for 2 days. The resulting ester, isolated in the usual manner, was hydrolysed without distillation by refluxing for 24 hours with 20 c.c. of constant-boiling hydrochloric acid. On cooling, 0·7 g. of a solid, m. p. 132—134°, crystallised; recrystallisation showed this to be suberic acid, m. p. and mixed m. p. 137°.

8-Ketononoic Acid.—The following conditions give a rather better yield than that of Barger, Robinson, and L. H. Smith. 85 G. of ethyl 6-bromohexoate were added to ethyl sodioacetoacetate prepared from sodium (7·5 g.), absolute alcohol (75 g.), and ethyl acetoacetate (45 g.). After refluxing overnight, the product was worked up in the usual way,

65 g. (63%) of ethyl α-acetylsuberate, b. p. 200°/2—3 mm., being obtained. This was refluxed for 20 hours with 50 c.c. of concentrated hydrochloric acid and 100 c.c. of water. After distillation, the fraction, b. p. 165—170°/1·5 mm., was freed from neutral material by means of sodium bicarbonate solution; redistillation then gave 28 g. (68%) of 8-ketononoic acid, b. p. 148°/0·8 mm., m. p. 40° (Found: C, 62·8; H, 9·3; equiv., 173·6. Calc.: C, 62·8; H, 9·3; equiv., 172). Barger, Robinson, and L. H. Smith give m. p. 40·5—42°. The ethyl ester boiled at 145—147°/15 mm. (Found: C, 66·0; H, 10·0. Calc.: C, 66·0; H, 10·0%).

Addition of Hydrogen Bromide.—The general procedure followed that used in our previous work. The hydrogen bromide was, however, prepared by the method of Ruhoff, Burnett, and Reid ("Organic Syntheses," 1935, **15**, 35). It was dried over phosphoric oxide and freed from bromine by means of a long column of copper turnings. The apparatus was so arranged that the current of hydrogen bromide could be replaced or augmented by either hydrogen or oxygen. The additions were carried out in U-tubes fitted with ground-glass joints and cooled at 0°. Before the reaction these were swept out with either hydrogen or oxygen. The passage of hydrogen bromide was continued until an excess had been taken up. The product was kept overnight, and the solvent and excess of reagent removed. When a solid bromo-acid was formed, it was, if possible, identified by direct comparison. More generally, the bromo-acid was esterified by the method of Wohlgemuth (*Ann. Chim.*, 1914, **2**, 298), and the distilled bromo-ester condensed with ethyl sodiomalonate as previously described (J., 1933, 573); it was generally desirable to remove low-boiling products (lactone, etc.) by distillation. The resulting tribasic ester was hydrolysed by refluxing with concentrated hydrochloric acid (5 vols.); the dibasic acid was identified by direct comparison.

(1) Δ^4-Pentenoic acid in hexane; hydrogen; no catalyst. Two experiments were carried out; in the first a little free bromine was allowed to pass over with the hydrogen bromide; in the second it was rigorously excluded. In both cases δ-bromovaleric acid, m. p. and mixed m. p. 40°, was obtained.

(2) Same acid in hexane; hydrogen; diphenylamine (1%). 2·6 G. of acid. Esterification of the oily bromo-acid gave 0·8 g. of bromo-ester, b. p. 122—126°/22 mm. Malonation and hydrolysis gave 0·2 g. of dibasic acid; crystallisation from benzene–light petroleum (b. p. 60—80°) gave pimelic acid, m. p. and mixed m. p. 104°.

(3) Δ^6-Heptenoic acid; no solvent; hydrogen; no catalyst. 2·8 G. of acid. The bromo-ester (3·6 g.) had b. p. 135°/17 mm.; malonation and hydrolysis gave 1·2 g. of dibasic acid, m. p. 63—66°. Recrystallisation from benzene–light petroleum gave an acid, m. p. 78°, mixed m. p. with β-methylsuberic acid 83°.

(4) Same acid in hexane; hydrogen; no catalyst. 2·3 G. of acid. The bromo-acid (3·2 g.), m. p. 17—19°, gave 2·1 g. of bromo-ester, b. p. 144—145°/22 mm. (Found: Br, 32·7. Calc. for $C_9H_{17}O_2Br$: Br, 33·8%). Malonation gave 2·0 g. of tribasic ester, b. p. 138—144°/27 mm., hydrolysis of which gave 1·7 g. of dibasic acid. After one crystallisation from benzene–light petroleum this had m. p. 104—105°, mixed m. p. with azelaic acid 105°.

(5) Same acid in acetic acid; hydrogen; no catalyst. 9·7 G. of acid. The bromo-acid (15·8 g.) gave, on esterification, 14·3 g. of bromo-ester, b. p. 132°/14 mm. Malonation and hydrolysis gave 3 g. of dibasic acid, m. p. 80°; one crystallisation from benzene–light petroleum gave β-methylsuberic acid, m. p. 82°, mixed m. p. 83°.

(6) Same acid, no solvent; oxygen; benzoyl peroxide (1%). 2·2 G. of acid. The bromo-ester (2·7 g.), b. p. 129—132°/13 mm., gave, on malonation and hydrolysis, 1·4 g., m. p. 95—100°. Crystallisation from benzene–light petroleum gave azelaic acid, m. p. and mixed m. p. 105°.

(7) Same acid in hexane; hydrogen; diphenylamine (1%). 2·3 G. of acid. The bromo-ester (2·5 g.), b. p. 130°/10 mm., gave, on malonation and hydrolysis, 0·4 g. of acid, m. p. 100—102°. Crystallisation from benzene–light petroleum gave azelaic acid, m. p. and mixed m. p. 104°.

(8) Δ^8-Nonenoic acid; no solvent; hydrogen; no catalyst. 4·1 G. of acid gave 3·4 g. of bromo-acid. The bromo-ester (2·7 g.), b. p. 146—48°/8 mm., gave, on malonation, 1·0 g. of tribasic ester, b. p. 195—200°/4 mm. Hydrolysis gave 0·5 g. of dibasic acid, m. p. 65—75°; crystallisation, first from benzene–light petroleum and then from dilute acetic acid, gave β-*methylsebacic acid*, m. p. 75—76° (Found: C, 61·0; H, 9·4. $C_{11}H_{20}O_4$ requires C, 61·1; H, 9·2%).

(9) Same acid in acetic acid; hydrogen; no catalyst. 4·2 G. of acid gave 6·3 g. of bromo-acid. The bromo-ester (5·9 g.), b. p. 142—146°/8 mm., gave, on malonation, 1·5 g. of tribasic ester, b. p. 160—165°/0·6 mm. Hydrolysis gave 0·7 g. of dibasic acid; crystallisation from

benzene–light petroleum gave two products. The more soluble was crystallised from dilute acetic acid and identified as β-methylsebacic acid, m. p. and mixed m. p. 73—76°. The less soluble was recrystallised from water and identified as nonane-1 : 9-dicarboxylic acid, m. p. 107°, mixed m. p. 109°. An authentic specimen of this compound was prepared by oxidation of ω-hydroxyundecoic acid, for a sample of which we are much indebted to Professor A. C. Chibnall, F.R.S.

(10) Same acid in hexane; hydrogen; no catalyst. 1 G. of acid. Esterification of the bromo-acid gave 1·4 g. of bromo-ester, b. p. 150—152°/9 mm. Malonation and hydrolysis gave 0·4 g. of dibasic acid; crystallisation from benzene–light petroleum, and then from water, gave nonane-1 : 9-dicarboxylic acid, m. p. and mixed m. p. 110°.

(11) Same acid in hexane; hydrogen; diphenylamine (1%). 4·3 G. of acid. Esterification of the bromo-acid gave 6 g. of bromo-ester, b. p. 148—152°/8 mm. Malonation gave 3·2 g. of tribasic ester, b. p. 165—175°/0·2—0·4 mm., which on hydrolysis gave a dibasic acid, m. p. 105°, mixed m. p. with nonane-1 : 9-dicarboxylic acid 108—110°.

(12) Same acid; no solvent; oxygen; benzoyl peroxide (1%). 3 G. of acid gave 3·5 g. of solid *9-bromo-n-nonoic acid*, m. p. 37—38° (Found: Br, 34·0. $C_9H_{17}O_2Br$ requires Br, 33·8%). Esterification gave 3·0 g. of bromo-ester, b. p. 150—154°/10 mm., which, on malonation, gave 2·9 g. of tribasic ester, b. p. 175—180°/1 mm. Hydrolysis and recrystallisation from benzene–light petroleum gave nonane-1 : 9-dicarboxylic acid, m. p. 107°, mixed m. p. 107—108°.

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417. *Methylation of Glucosamine.*

By W. O. Cutler, W. N. Haworth, and S. Peat.

It seems probable that aminohexoses appear as part of the structure of some immunopolysaccharides. This being so, it is desirable to investigate suitable crystalline reference compounds which may prove useful in the identification of glucosamine in this type of substance. Methods are given for the preparation of trimethyl glucosamine and several of its derivatives and their properties are described.

Direct attempts to protect the hydroxyl groups of glucosamine by methylation have hitherto achieved little success. For the attainment of this result it would seem to be a necessary condition to diminish the activity of the amino-group. Without this precaution the use of methyl sulphate as methylating agent introduces far-reaching decomposition of the glucosamine which may or may not be accompanied by methylation of the fragments.

In the hope that the required condition might be achieved by the formation of Schiff's bases the properties of three of these compounds were studied, namely *o*-hydroxybenzylidene-, *p*-methoxybenzylidene-, and benzylidene-glucosamine. The last-named has not previously been described. In respect of ease of hydrolysis the three substances were similar, decomposition of each into the original aldehyde and glucosamine being effected by boiling water, dilute acids, and cold dilute alkali. Their instability to alkali rendered these bases unsuitable for the purpose of methylation in aqueous alkali solution, and a fruitless attempt was made to methylate benzylideneglucosamine by treatment in liquid ammonia with potassium and methyl iodide.

On the other hand *N*-acetylglucosamine is known to be comparatively stable in the presence of alkali. It was found from a study of the penta-acetyl glucosamine that the *O*-acetyl groups were easily eliminated by cold alkali with the formation of mono- or *N*-acetylglucosamine. These conditions appeared suitable for the preparation *in situ* of a modified glucosamine of the type required and a successful outcome of the process of methylation in alkaline solution seemed possible. After preliminary trials conditions were found for the conversion of penta-acetyl glucosamine into a crystalline methyl derivative

by the action of methyl sulphate and sodium hydroxide. This product, m. p. 195°, contained one acetyl group and four methoxyl groups. It did not reduce Fehling's solution or give a coloration with Ehrlich's reagent; and a van Slyke estimation showed the absence of a primary amino-group, although nitrogen was present. To this substance is assigned the constitution of N-*acetyl trimethyl* β-*methylglucosaminide* and this is supported by its properties.

The same substance was obtained in much better yield by an alternative route. Acetobromoglucosamine hydrobromide was converted by the method of Irvine, McNicoll, and Hynd (J., 1911, **99**, 260) into the corresponding α-methylglucoside. By treatment of the latter in methyl-alcoholic solution with acetic anhydride in the presence of silver acetate, N-*acetyl triacetyl* β-*methylglucosaminide* (m. p. 159°) was obtained in 90% yield. Methylation of this substance at 50° in carbon tetrachloride solution gives *N*-acetyl trimethyl β-methylglucosaminide in excellent yield. The product was identical with that obtained by the methylation of glucosamine penta-acetate and the over-all yield from glucosamine hydrochloride is three times as great.

The glucosamine penta-acetate used in these experiments was a mixture of α- and β-forms, but the β-configuration is given to the glucoside because of its low specific rotation ($[\alpha]_D$ − 13·1° in methyl alcohol) and because it can be converted by boiling with 2% methyl-alcoholic hydrogen chloride into a substance, m. p. 150°, which, in most of its properties, appeared to be isomeric with the original material and it showed a higher rotation ($[\alpha]_D$ + 135° in methyl alcohol). This substance is considered to be N-*acetyl trimethyl* α-*methylglucosaminide*. When the α-glucoside or the original β-glucoside is boiled with 7% methyl-alcoholic hydrogen chloride, the acetyl group is removed and the product is *trimethyl* α-*methylglucosaminide hydrochloride*, from which, by treatment with sodium bicarbonate, the free *amine* is obtained as a colourless distillable syrup. The process may be reversed by boiling the syrup for a short time with 2% methyl-alcoholic hydrogen chloride, the crystalline α-methylglucosaminide then being re-formed. The hydrochloride and amine are both regarded as α-glucosides, since each is converted by the action of acetic anhydride and sodium acetate into *N*-acetyl trimethyl α-methylglucosaminide unaccompanied by any of the β-form.

Hydrolysis of the β-methylglucosaminide with hydrochloric acid removed both the *N*-acetyl group and the glycosidic methyl group, the crystalline product being *trimethyl glucosamine hydrochloride*. Conditions for the regeneration of the glucoside by treatment with methyl-alcoholic hydrogen chloride were not established.

At this stage it is undesirable to ascribe constitutional formulæ to the substances described inasmuch as experiments are in progress to determine the ring structure and configuration of them. For example, despite the work of numerous authors on the subject we prefer not to regard as settled the question of the configuration of the amino-group. The stability of the *N*-acetyl group in some of these compounds suggests a possible ortho-acetic acid linking, but this also must be the subject of further work.

Experimental.

Methylation of Glucosamine Penta-acetate.—Glucosamine hydrochloride from crab shell was acetylated by acetic anhydride and sodium acetate under the conditions prescribed by Lobry de Bruyn and van Ekenstein (*Rec. trav. chim.*, 1899, **18**, 83) and a crystalline mixture of the α- and the β-form of penta-acetyl glucosamine was obtained. One sample of the penta-acetate showed $[\alpha]_D^{20^\circ}$ + 51·5° (*c*, 0·48 in chloroform). The *N*-acetyl group of glucosamine penta-acetate was not removed by contact with N-sodium hydroxide at room temperature for 2 hours, although hydrolysis of the *O*-acetyl groups occurred under these conditions. At 50°, however, all five acetyl groups were removed by N-sodium hydroxide.

Glucosamine penta-acetate (5 g.) was vigorously stirred at room temperature with carbon tetrachloride (50 c.c.) and water (50 c.c.). To this cold mixture was then added simultaneously, in ten aliquot parts, methyl sulphate (50 c.c.) and 40% sodium hydroxide solution (120 c.c.). The addition was made with extreme slowness, and the temperature kept at 15—20° until the mixture became non-reducing. This stage was reached after the addition of two-tenths of the reagents over the course of 2 days. Thereafter the temperature was raised to 35—40°, and the

remainder of the methylating agents added over a period of 3 hours. The mixture was then boiled for 20 minutes to complete the reaction. The cooled alkaline solution was neutralised in presence of ice with 10% sulphuric acid and thoroughly extracted with chloroform. Removal of the chloroform from the dried extract left a solid residue, which was recrystallised from ethyl acetate. Yield, 1—1·5 g. This product had m. p. 195°; $[\alpha]_D^{21°}$ + 19·6° in chloroform (*c*, 0·306), $[\alpha]_D^{16°}$ − 29·0° in water (*c*, 0·28), and $[\alpha]_D^{20°}$ − 13·1° in dry methyl alcohol (*c*, 0·306). It was non-reducing to Fehling's solution, failed to give the Ehrlich reaction (with *p*-dimethylaminobenzaldehyde) and a van Slyke estimation revealed the absence of free amino-nitrogen. The substance showed a remarkable stability to alkali, being recovered unchanged after boiling with 15% sodium hydroxide solution. These properties, together with others described below, were consistent with the formulation of the substance as N-*acetyl trimethyl* β-*methylglucosaminide* (Found: C, 51·75; H, 8·3; N, 5·05; OMe, 45·0. $C_{12}H_{23}O_6N$ requires C, 52·0; H, 8·3; N, 5·05; OMe, 44·8%).

The yield of methylated product by this method is not good and there evidently occurs complete destruction of a part of the penta-acetate. On the supposition that this destruction is an oxidative process, the methylation was conducted in a number of cases in an atmosphere of nitrogen, but no improvement in yield was effected. Nor was this end achieved by substitution of other solvents such as acetone for the carbon tetrachloride. A slightly increased yield was, however, obtained when the temperature of methylation was not allowed to rise above 40°; that is, when the final boiling process was omitted. In this case, the hydrolysis of the excess of methyl sulphate was effected by continuation of the stirring for 24 hours at room temperature.

Improved Method of Preparation of N-*Acetyl Trimethyl* β-*Methylglucosaminide*.—*l*-Bromotriacetyl glucosamine hydrobromide was prepared by the method of Irvine, McNicoll, and Hynd (*loc. cit.*). This was sufficiently pure after one recrystallisation for the subsequent reactions. A specimen was, however, purified further by repeated crystallisation from chloroform–ether. This specimen had m. p. 149—150° (softening at 144°) and $[\alpha]_D^{19°}$ + 148·0° in acetone (*c*, 0·84). It was soluble in water, methyl alcohol, ethyl alcohol, acetone, and ethyl acetate, and was insoluble in ether, light petroleum and benzene.

Triacetyl β-methylglucosaminide hydrobromide was prepared from bromotriacetyl glucosamine hydrobromide by the method of Irvine, McNicoll, and Hynd (*loc. cit.*). After recrystallisation from methyl alcohol containing a little ether it melted with decomposition at 230—233°.

Acetylation of triacetyl β-*methylglucosaminide*. Three methods of acetylation were tried, namely, by heating with acetic anhydride and sodium acetate; with acetic anhydride and zinc chloride; and by treatment with acetic anhydride in methyl-alcoholic solution. The yields by the three methods were respectively 50, 50, and 90%. The third method was adopted in the routine procedure and conducted as follows. A mixture of triacetyl β-methylglucosaminide hydrobromide (0·4 g.) with silver acetate (0·17 g.; 1 mol.), acetic anhydride (1 c.c.; 2 mols.), and methyl alcohol (8 c.c.) was shaken for 12 hours at room temperature and thereafter filtered. Water was added to the filtrate, and the solution neutralised with sodium bicarbonate. The neutral solution was then extracted repeatedly with chloroform, and the solvent removed from the dried extract. The product was recrystallised from ether–petrol and ethyl alcohol. It was a non-reducing crystalline *substance*, m. p. 159°, $[\alpha]_D^{17°}$ − 21·0° in methyl alcohol (*c*, 0·38). It was soluble in chloroform, the alcohols, and ethyl acetate, and insoluble in ether, petrol, or carbon tetrachloride (Found: C, 50·0; H, 6·5. $C_{15}H_{23}O_9N$ requires C, 49·9; H, 6·4%).

Methylation of N-*acetyl triacetyl* β-*methylglucosaminide*. *N*-Acetyl triacetyl β-methylglucosaminide (2 g.) was treated in aqueous solution (50 c.c.) with carbon tetrachloride (50 c.c.), methyl sulphate (50 c.c.), and 40% sodium hydroxide solution (120 c.c.) at 50°. The methylating agents were added in ten aliquot parts over a period of 3½ hours. The product, extracted in the usual way, was a white crystalline solid (yield, 1 g.). The mother-liquors were subjected to a second methylation treatment and a further quantity (0·5 g.) of the crystalline product was isolated. The total yield was thus 95% of the theoretical quantity. The product was *N*-acetyl trimethyl β-methylglucosaminide, m. p. 195°, identical with that prepared by the methylation of glucosamine penta-acetate (no depression of m. p. by admixture) (Found: C, 51·9; H, 8·3; OMe, 44·4. Calc.: C, 52·0; H, 8·3; OMe, 44·8%).

Behaviour of N-*Acetyl Trimethyl* β-*Methylglucosaminide with Acids*.—(a) *Action of* 5% *hydrochloric acid*. In the cold no action occurred when the crystalline methylated compound (1·0 g.) was dissolved in 5% hydrochloric acid (50 c.c.), but when the temperature was raised to 95—100°, reducing properties developed and the specific rotation changed from −15° to +219° in 3 hours. The solution was then neutralised by keeping it in contact with an excess of lead carbonate for 12 hours. After filtration and removal of the lead by the usual method with

hydrogen sulphide, the solution was treated with the theoretical quantity of hydrochloric acid to form the hydrochloride. The acid solution was taken to dryness under diminished pressure, and the residue crystallised. After recrystallisation from ethyl alcohol–ether, the substance showed the properties of *trimethyl glucosamine hydrochloride*. It decomposed without melting at 210°, contained ionisable chlorine, reduced Fehling's solution, and was unstable to alkali. In methyl alcohol (*c*, 0·42 g.) it showed $[\alpha]_D^{16°}$ + 56·8°. In water (*c*, 1·2) mutarotation was observed, $[\alpha]_D^{19°}$ + 49·2 → +99·4° in 280 minutes (Found: C, 42·1; H, 7·9; N, 5·5; OMe, 36·0; Cl, 14·3. $C_9H_{19}O_5N,HCl$ requires C, 42·1; H, 7·8; N, 5·45; Cl, 13·8%). In a van Slyke estimation of amino-nitrogen 4·0 mg. of the substance gave 0·35 c.c. of nitrogen ($C_9H_{17}O_5NH_2,HCl$ gives 0·35 c.c.).

The trimethyl glucosamine hydrochloride was boiled for 36 hours with methyl alcohol containing 2% of hydrogen chloride. No glucosaminide was formed, the trimethyl glucosamine hydrochloride being recovered unchanged.

(b) *Action of* 1% *methyl-alcoholic hydrogen chloride.* *N*-Acetyl trimethyl β-methylglucosaminide (0·099 g.) was dissolved in 1% methyl-alcoholic hydrogen chloride (10 c.c.), and the solution heated on the water-bath under reflux until the rotation became constant. The following rotation changes were recorded:

Time of heating (mins.)	0	50	90	150	210	290
$[\alpha]_D$	− 2·0°	+ 24·2°	+ 45·4°	+ 64·6°	+ 80·8°	+ 99·0°
Time of heating (mins.)	345	420	495	555	615	
$[\alpha]_D$	+114·0°	+125·2°	+134·0°	+135·4°	+135·4°	

The reaction was thus complete in 9¼ hours and the rotation of the product shows it to be identical with that isolated after treatment with 2% methyl-alcoholic hydrogen chloride (see below).

(c) *Action of* 2% *methyl-alcoholic hydrogen chloride.* *N*-Acetyl trimethyl β-methylglucosaminide (0·5 g.) was heated under reflux for 12 hours with dry methyl alcohol (50 c.c.) containing hydrogen chloride (1 g.). The solution was then neutralised (lead carbonate) and filtered, the solvent evaporated, and the residue extracted with chloroform. The chloroform solution was filtered and evaporated, and the residue once more taken up in a small amount of chloroform. To this solution was added light petroleum until a turbidity appeared. On standing overnight in a refrigerator a crystalline product separated and this was purified by recrystallisation from ethyl acetate. The yield of this compound is 90% of the weight of β-glucosaminide taken. M. p. 150°; $[\alpha]_D^{18°}$ +120·0° in chloroform (*c*, 0·4), $[\alpha]_D^{20°}$ +104·3° in water (*c*, 0·92), and $[\alpha]_D^{21°}$ +135·0° in dry methyl alcohol (*c*, 0·62). It was non-reducing and contained nitrogen, but a van Slyke estimation showed the absence of amino-nitrogen. It gave no coloration with the Ehrlich reagent and was stable to boiling alkali, but was decomposed easily by aqueous acid. The high rotation and the m. p. differentiate this substance from the starting material and the properties suggested that it was N-*acetyl trimethyl α-methylglucosaminide*. This was supported by ultimate analysis (Found for two samples: C, 52·3, 52·3; H, 8·5, 8·5; N, 4·9, 5·0; OMe, 43·5, 44·0. $C_{12}H_{23}O_6N$ requires C, 52·0; H, 8·3; N, 5·05; OMe, 44·8%).

(d) *Action of* 7% *methyl-alcoholic hydrogen chloride.* The expected removal of the acetyl group by hydrolysis was only achieved when more concentrated acid was used. Thus, when *N*-acetyl trimethyl β-methylglucosaminide was refluxed for 24 hours with methyl alcohol containing 7% of hydrogen chloride, a mixture of the glucoside, m. p. 150°, and *trimethyl α-methylglucosaminide hydrochloride* was obtained, the latter constituting 90—95% of the mixture. To isolate the hydrochloride, the product obtained after neutralisation of the mineral acid with lead carbonate and removal of the methyl alcohol was treated in one of two ways: (1) It was shaken with cold ethyl acetate, which dissolved the acetyl compound, leaving the methylated glucosamine hydrochloride, which is practically insoluble in this solvent; or (2), it was dissolved in a small volume of chloroform, and the solution treated with an excess of ether, the hydrochloride being immediately precipitated and the acetyl compound remaining in solution.

The trimethyl α-methylglucosaminide hydrochloride so obtained softened at 210° and decomposed at 237°; $[\alpha]_D^{20°}$ + 129·6° in water (*c*, 0·54) and $[\alpha]_D^{22°}$ + 113·6° in methyl alcohol (*c*, 0·22). It was non-reducing, gave a negative Ehrlich reaction, and contained nitrogen, ionised chlorine, and a primary amino-group. In a van Slyke estimation, 2·56 mg. gave 0·24 c.c. of amino-nitrogen ($C_{10}H_{21}O_5N,HCl$ requires 0·21 c.c.) (Found: C, 44·1; H, 8·2; N, 5·3; Cl, 13·0; OMe, 44·8. $C_{10}H_{21}O_5N,HCl$ requires C, 44·2; H, 8·1; N, 5·2; Cl, 13·0; OMe, 45·7%).

Deacetylation of N-*Acetyl Trimethyl α-Methylglucosaminide.*—This was effected in the same manner as for the β-glucoside by boiling with 7% methyl-alcoholic hydrogen chloride. The

product was trimethyl α-methylglucosaminide hydrochloride identical in m. p. and rotation with that obtained above.

Acetylation of Trimethyl α-Methylglucosaminide Hydrochloride.—The hydrochloride (48 mg.) was refluxed for 15 minutes with acetic anhydride (2 c.c.) and fused sodium acetate (50 mg.). The mixture was poured into water and neutralised with sodium bicarbonate, and the solution extracted with chloroform. After drying over anhydrous sodium sulphate, the chloroform was removed from the extract, and the residue recrystallised from ethyl acetate. It was *N*-acetyl trimethyl α-methylglucosaminide, m. p. 150°; $[\alpha]_D$ + 135° in methyl alcohol. Yield, 45 mg.

Isolation of the Free Amine.—Trimethyl α-methylglucosaminide hydrochloride (0·38 g.) was dissolved in water (20 c.c.) and treated with a slight excess of sodium bicarbonate. After 3 hours the solution was exhaustively extracted with chloroform, the extract dried, and the solvent removed. The product, *trimethyl α-methylglucosaminide*, was a pale mobile syrup (0·35 g.). The amine was stable to heat and was purified by distillation at 0·004 mm. pressure (bath temperature, 85°). The distillate was a colourless mobile syrup showing $n_D^{23.5°}$ 1·4555 and $[\alpha]_D^{22°}$ + 169·8° in dry methyl alcohol (*c*, 0·79) (Found: OMe, 52·1. $C_{10}H_{21}O_5N$ requires OMe, 52·8%).

Acetylation of the Free Amine.—Trimethyl α-methylglucosaminide (40 mg.) was heated with acetic anhydride (5 c.c.) and fused sodium acetate (50 mg.), and the acetylation product isolated as before. After recrystallisation from ethyl acetate it melted at 150° and had $[\alpha]_D$ + 135° in methyl alcohol. It was thus *N*-acetyl trimethyl α-methylglucosaminide. Yield, 37 mg.

Formation of the Hydrochloride.—Trimethyl α-methylglucosaminide (40 mg.) was refluxed for 10 minutes with 2% methyl-alcoholic hydrogen chloride (30 c.c.). Thereafter the excess of mineral acid was neutralised with lead carbonate, and the filtered solution taken to dryness. The residue was dissolved in chloroform and precipitated by the addition of light petroleum. The crystalline precipitate, separated in a centrifuge, was washed twice with ether and dried in a vacuum desiccator. It was trimethyl α-methylglucosaminide hydrochloride. Yield, 35 mg.

Condensation of Glucosamine with Aromatic Aldehydes.—Salicylideneglucosamine was prepared by the method of Irvine and Earl (J., 1922, **121**, 2376). Similarly, *p*-methoxybenzylideneglucosamine was obtained by the procedure of Bergmann and Zervas (*Ber.*, 1931, **64**, 975). Each of these Schiff's bases was easily hydrolysed by both acid and alkali. It was found possible to prepare a simpler Schiff's base by the condensation of glucosamine with benzaldehyde. Glucosamine hydrochloride (2 g.) was shaken for several hours at room temperature with a mixture of freshly distilled benzaldehyde (1·1 c.c.) and *N*-sodium hydroxide (9·4 c.c.). A crystalline solid which separated during this operation was collected, washed with ice-cold water and with alcohol–ether, and recrystallised from ethyl alcohol. Yield, 2·4 g.; m. p. 156° (decomp.). Benzylideneglucosamine was insoluble in ether, chloroform, acetone, or cold dioxan, and soluble in methyl or ethyl alcohol and hot dioxan. It was also soluble in pyridine, but solution was accompanied by liberation of benzaldehyde. With a view to its subsequent methylation the hydrolysis of benzylideneglucosamine was studied. It was found to be hydrolysed by dilute acids, by boiling water and with particular ease by keeping in the presence of aqueous alkali. Thus despite the presence of alkali during the preparation of benzylideneglucosamine, benzaldehyde was liberated by N-sodium hydroxide and by sodium bicarbonate in the cold, by warm silver oxide in methyl alcohol, by potassium carbonate in boiling ethyl alcohol, and by sodium hydroxide in dioxan. The Schiff's base was not, however, decomposed by sodium bicarbonate in boiling ethyl alcohol. These properties indicated the unsuitability of benzylideneglucosamine for methylation by the usual method, but an attempt was made to methylate the substance by treating it in liquid ammonia successively with potassium and methyl iodide. The product was a dark syrup which contained only 3·2% OMe.

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EDGBASTON.
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418. *Polysaccharides. Part XXVI. Xylan.*

By R. A. S. BYWATER, W. N. HAWORTH, E. L. HIRST, and S. PEAT.

Earlier work of two of the authors has shown that xylan consists of linked chains of xylopyranose units terminated at one end by units of arabofuranose. Removal of this terminal group exposes what was formerly a penultimate group of xylopyranose

and this now becomes the new end-group in these linked chains. This new end-group has been evaluated by assay of the crystalline trimethyl xylopyranose and the former estimate of the basal chain length is confirmed.

It was established by Haworth, Hirst, and Oliver (J., 1934, 1917) that *l*-arabofuranose was present in xylose as a terminating unit, there being one such unit to 18—20 *d*-xylopyranose residues. The significance of this observation was discussed and an opportunity was taken to examine again the validity of the end-group method in the determination of polysaccharide structure. It was also emphasised that a straight terminated chain is only one of a number of possible structures for a methylated polysaccharide which has been shown to yield a recognisable "end-group". The work now described represents an attempt to decide between these various structural arrangements or to limit their number. Xylan was chosen for this purpose, since the terminating group in this polysaccharide is distinguished sharply from the remaining residues of the chain in that it is a configurationally different sugar and exists in a different ring form (furanose). Inasmuch as a furanoside link is more susceptible to acid hydrolytic agents than is a pyranoside union it was conjectured that conditions might be found which would enable the arabofuranose unit to be removed by hydrolysis from the xylan molecule without disturbance of the xylopyranoside linkages, and these conditions have been realised. Treatment of xylan with 0·2% aqueous oxalic acid at 100° effects complete removal of the arabinose fragment without the liberation of any detectable xylose.

The arabinose-free xylan so prepared showed an enhanced reducing power. It was methylated by the method of Haworth, Hirst, and Oliver, and a careful fractionation of the product in a chloroform–ether–light petroleum mixture showed it to be essentially homogeneous. The main fraction of methylated arabinose-free xylan (which was subsequently hydrolysed) showed a methoxyl content of 38·3% (calculated for a dimethyl pentosan, 38·9%) and had $[\alpha]_D^{21^\circ} - 91{\cdot}2^\circ$ in chloroform (methylated xylan has $[\alpha]_D^{20^\circ} - 98{\cdot}3^\circ$).

Complete hydrolysis of methylated arabinose-free xylan was achieved by boiling with 1·2% methyl-alcoholic hydrogen chloride and the resulting mixture of methylated methylxylosides was separated by fractional distillation. The yield of trimethyl methylxylopyranoside was estimated as 7%, corresponding to a chain length of 18—19 xylose units in the polysaccharide. Indisputable proof is thus afforded that in the process of removing the arabinose residue from xylan no material degradation of the basal chain units occurs.

In a number of preliminary experiments, nitric acid solutions of various dilutions were also used as hydrolytic agents, but the results were not so conclusive as in the experiments with oxalic acid. No hydrolysis of the xylopyranoside linkages occurred when xylan was boiled with N/200-nitric acid, but, at this concentration of acid, the removal of the arabinose residue was only partly effected. The product, referred to in the experimental section as xylan A, yielded on methylation and subsequent hydrolysis a trimethyl pentose fraction which was shown to be a mixture of trimethyl arabofuranose and trimethyl xylopyranose. The partial removal of arabinose from xylan by nitric acid hydrolysis does not materially affect the viscosity of derivatives of the xylan A so produced.

It is clear from the experiments described that the hydrolytic removal of the arabofuranose end-group from xylan exposes a xylose unit which now functions as an end-group and gives rise to the trimethyl methylxyloside isolated after methylation and hydrolysis. It follows that xylan must contain the structure arabofuranose-xylopyranose-(main chain) and that a continuous loop of xylose units with side-chains of arabofuranose residues is excluded as a possibility.

Methylated arabinose-free xylan shows a viscosity which is only half of that of methylated xylan. This fall in viscosity is accompanied by a corresponding increase in the reducing power of the polysaccharide. Table I makes this clear and it is to be observed that chain length as determined by the end-group method is substantially the same for xylan, xylan A, and arabinose-free xylan.

The observations recorded point to a structure for xylan in which primary chains of the form arabofuranose-(xylose)$_{16-17}$-xylose are linked together by some type of union involving the free xylose reducing group and a hydroxyl group in a second chain. The fact that 2-monomethyl xylose always accompanied the trimethyl pentose and that the amounts of each are similar lends some support to this hypothesis and further suggests that the link occurs between the reducing group of one primary chain and the 3-position of a xylose residue in another chain. The nature of this linkage between the primary chains is still a matter for speculation. It would seem at least to be a link which is relatively stable to the action of the alkaline methylating agents, although this stability (as measured by the degree of aggregation) is adversely affected under the conditions described by the removal of the arabofuranose. Nevertheless the latter cannot itself participate in the linkage, inasmuch as it functions as an end-group.

Experience indicates that this assembly of primary terminated chains into larger complexes is a structural development common to most, if not all, polysaccharides (Haworth, Hirst, and Oliver, *loc. cit.*; Haworth, Hirst, and Isherwood, this vol., p. 784). The views expressed and their detailed formulation in these and in earlier papers from this laboratory are supported in the present case. In addition, the significance of the effect of the terminating non-reducing unit (the arabofuranose) of the primary xylan chains upon the tendency to mutual combination of those chains may assume importance and must be taken into account in any attempt to determine the nature of the linkages responsible for the union of several chains.

EXPERIMENTAL.

Removal of Arabofuranose Residue from Xylan.—The xylan used in the following experiments was prepared from esparto half-stuff kindly supplied to us by Messrs. Alexander Pirie & Co. of Bucksburn. It conformed exactly in its properties with the samples of xylan previously described (Hampton, Haworth, and Hirst, J., 1929, 1739; Haworth, Hirst, and Oliver, *loc. cit.*). Dilute nitric acid was found to be a suitable hydrolytic agent. In order to ascertain the conditions most favourable for removal of the arabinose residue without degradation of the xylan, preliminary experiments were performed as follows: A solution of xylan (*c*, 1·0) in nitric acid of various strengths was boiled for 1 hour, and the solution was then made alkaline by addition of 12% aqueous sodium hydroxide so that in the final solution the concentration of sodium hydroxide was 6%. The rotation of the solution was then determined. With nitric acid concentrations between N/150 and N/200 the final rotation was $[\alpha]_D^{20°}$ − 102°, but with acid stronger than N/100 lower rotations were observed and hydrolysis of the xylose residues took place. In 6% sodium hydroxide solution the rotation of ordinary xylan is − 108°. It appeared therefore that hydrolysis by N/200-nitric acid would be most likely to remove the arabofuranose without disturbance of the rest of the molecule.

Strength of HNO_3	N/1	N/10	N/50	N/100	N/150	N/200
Final $[\alpha]_D$	+20°	−50°	−85°	−98°	−102°	−102°

Xylan (20 g.) was boiled for 1 hour with N/200-nitric acid (2 l.). The colloidal solution was cooled and centrifuged. The solid was triturated successively with water, alcohol, and ether and dried in a vacuum (17·5 g.). In this way 175 g. of xylan A were collected, $[\alpha]_D^{21°}$ − 111° in 6% sodium hydroxide solution (*c*, 1·3), iodine number 1·5 (the original xylan had $[\alpha]_D^{22°}$ − 109·5° and an iodine number 1·1).

The clear liquid in the centrifuge tubes was neutralised with sodium carbonate and concentrated to a small volume. Addition of alcohol precipitated some xylan which had remained in solution and removal of the solvent then left a syrup, which was extracted with boiling 90% alcohol. The alcohol was distilled off, leaving a strongly reducing syrup. Estimation of the reducing power of this crude syrup by Fehling's solution showed that 5% of the original xylan had been converted into reducing sugar (calculated as arabinose). Proof that the reducing sugar was arabinose was obtained by dissolving the syrup (0·5 g.) in water (2 c.c.) and adding alcohol containing benzylphenylhydrazine (0·65 g.). The solution was warmed (15 mins.) and then kept at room temperature for 2 days. The yield of arabinose *benzylphenylhydrazone* (m. p. 171°, alone or when mixed with an authentic sample) was 0·5 g. But estimation of the reducing power (Fehling's method; Cole's ferricyanide method) of the syrup showed that 0·5 g. contained 0·3 g. of reducing sugar (calculated as arabinose). Now 0·3 g. of arabinose gave under similar conditions 0·54 g. of arabinose benzylphenylhydrazone.

It appears, therefore, that all the reducing sugar formed in the hydrolysis was arabinose, and the amount of it was such that the acid-treated xylan could retain only a portion of its original arabinose content. To distinguish this acid-treated xylan from ordinary xylan it is proposed to refer to it as xylan A.

Methylation of Xylan A.—Xylan A (10 g.) was ground to a paste with water (280 c.c.), water (600 c.c.) was then added, and potassium hydroxide (720 g.) was dissolved in the mixture. The heat liberated brought about solution of the xylan. Methylation was then carried out at 20° by gradual addition of methyl sulphate (800 c.c.), with stirring. The mixture frothed badly and this was controlled as far as posisble by addition of a few drops of amyl alcohol from time to time. After the completion of the reaction the mixture was heated at 100° for 1 hour, diluted with boiling water (1·5 l.), and filtered. The crude methylated xylan collected on the filter had OMe, 30%. After three successive methylations the product was thoroughly washed with boiling water and obtained as a white powder [ash content, 4·5%; OMe (corrected for ash content), 38·5%; yield, 95 g. from 150 g. of xylan].

For further purification the methylated material (94 g.) was dissolved in chloroform (1500 c.c.). The solution was centrifuged to remove insoluble inorganic impurities, and ether (1500 c.c.) was added to the clear solution. This precipitated fraction I (29 g.) as a brown jelly. A second fraction was then precipitated by addition of light petroleum to the solution (fraction II) (64 g.). These fractions were further separated by repetition of the process, giving finally the four fractions described in the following table.

Fraction.	Weight, g.	Ash, %.	OMe, %.*	$[\alpha]_D^{20°}$ in $CHCl_3$.	Apparent *M.W.*†
1	10·5	15	38·5	—	—
2	15·1	2·3	37·0	—	—
3	31·5	0·8	38·1	−92°	86 units
4	29·8	0·8	38·0	−92	88

* Corrected for ash content.
† From viscosity in *m*-cresol, using Staudinger's formula with $k = 10^{-3}$.

A portion of fraction (3) was further purified until it was ash-free. It then had m. p. 202° (ash-free methylated xylan containing the arabinose residue has m. p. 197°).

Hydrolysis of Methylated Xylan A.—The methylated derivative (fraction 3 and part of fraction 4; weight, 40·34 g.) was boiled with 1·2% methyl-alcoholic hydrogen chloride (1300 c.c.). After 10 hours the whole of the methylated xylan A had dissolved and after 15 hours the rotation became constant at $[\alpha]_D^{18°}$ + 57°. The product was isolated in the usual way (98% yield of methylated pentosides) and fractionated by distillation in a high vacuum, as follows:

Fraction	1	2	3	4	5	6	7
Weight, g.	0·766	0·850	1·117	1·255	5·475	11·898	12·821
$n_D^{21°}$	1·4388	1·4421	1·4475	1·4535	1·4555	1·4560	1·4560

The methoxyl content of fraction (1) (59·7%) showed it to consist entirely of trimethyl methylpentoside (Calc.: OMe, 60·2%), while the constancy of refractive index suggests that fractions (6) and (7) consist entirely of dimethyl methylpentoside. The yield of trimethyl methylpentoside, calculated on the basis of the following detailed examination of the fractions, corresponded to a chain length of 18—20 pentose units for xylan A.

Examination of the Trimethyl Methylpentoside.—Hydrolysis of fraction (1) (trimethyl methylpentoside) with N/15-hydrochloric acid at 100° was followed polarimetrically: $[\alpha]_D^{20°}$ − 21° (initial value); − 21° (30 mins.); − 14° (60 mins.); − 4° (90 mins.); + 1° (120 mins.); + 4° (150 mins.); + 5° (180 mins., constant for 60 mins.). The strength of the acid was then raised to N, and the hydrolysis continued. After a further 30 minutes the rotation had fallen to − 2°. From these results it was evident that the syrup was not pure trimethyl methylxyloside. That both trimethyl xylopyranose and trimethyl arabofuranose were present was proved in the following way, fraction (2), which was known to contain 20% by weight of dimethyl methylxyloside, being used. The syrup (1·3 g.) was heated with N/15-hydrobromic acid at 100° until the rotation was constant (4 hours). During this period any methylfuranoside present was hydrolysed. To the solution were added calcium carbonate (1 g.) and bromine (0·4 c.c.). After 3 days at 0° the solution was non-reducing. The excess of bromine was removed by aeration and the solution (X) was retained for further examination after extraction with chloroform. Evaporation of the chloroform extract left a syrup, which was distilled, giving: (a) 0·13 g., $n_D^{18°}$ 1·4420, b. p. 100°/1 mm. (bath temp.); (b) 0·3 g., $n_D^{18°}$ 1·4462, b. p. 100—110°/1 mm. (bath temp.); (c) 0·32 g., $n_D^{17°}$ 1·4560, b. p. 110—140°/0·1 mm. (bath temp.).

Hydrolysis of (a) with N-sulphuric acid at 100° was complete in 30 minutes ($[\alpha]_D + 18°$, final value). The neutralised solution was evaporated to dryness, and the product extracted with ether. After recrystallisation from ether–light petroleum it had m. p. 90° alone or when mixed with 2 : 3 : 4-trimethyl xylopyranose (yield, 0·03 g.). This proved that 2 : 3 : 4-trimethyl methylxyloside was present in the products obtained by hydrolysis of methylated xylan A.

Fraction (c) (above) was hydrolysed by N-hydrobromic acid at 85° and the reducing sugar so obtained was oxidised by bromine. The resulting 2 : 3-dimethyl xylonolactone was isolated as the corresponding crystalline amide, m. p. 133°, alone or when mixed with an authentic sample of 2 : 3-dimethyl xylonamide (for details, see Haworth, Hirst, and Oliver, *loc. cit.*). The presence of 2 : 3-dimethyl methylxyloside in fraction (2) was thus confirmed.

The neutral aqueous solution (X) (see above) remaining after extraction by chloroform was evaporated to dryness, and the residue made slightly acid and extracted with chloroform. Removal of the chloroform left a syrup, which was distilled, giving crystalline 2 : 3 : 5-trimethyl arabonolactone (0·1 g.), m. p. after recrystallisation from ether–light petroleum, 29°, $[\alpha]_D^{19°}$ − 38° in water ⟶ − 36° after 115 hours (Found : OMe, 47·4. Calc., 48·2%). Some 2 : 3 : 5-trimethyl arabofuranose was therefore present in the hydrolysis products. The relative proportion of trimethyl arabofuranose and trimethyl xylopyranose cannot be determined accurately, but in view of the rotations observed during the hydrolysis of fraction (1) the two sugars were present probably in the proportion of 2 to 1 respectively.

The identity of the 2 : 3-dimethyl methylxyloside, which formed the major part of the distillate (see above), was proved by its conversion into the lactone and amide of the corresponding 2 : 3-dimethyl xylonic acid. The amide, obtained in good overall yield, had m. p. 133°, $[\alpha]_D^{20°}$ + 46° in water (*c*, 1·2) (Found: OMe, 32%. Calc. for $C_7H_{15}O_5N$: OMe, 32·1%).

Monomethyl Xylose.—After distillation of the bulk of the dimethyl methylxyloside there remained a small amount of syrup, which distilled slowly at bath temp. 130°/0·02 mm., giving monomethyl methylxyloside (1·87 g. from 40·3 g. of mixed methylpentosides obtained after hydrolysis), $n_D^{18°}$ 1·4720 (Found : OMe, 34·5. $C_7H_{14}O_5$ requires OMe, 34·8%). The hydrolysis of this substance by N-hydrochloric acid at 95° was followed polarimetrically : $[\alpha]_D^{19°}$ + 84° (initial value, *c*, 1·6); 69° (15 mins.); 53° (30 mins.); 40° (45 mins.); 31° (75 mins.); 29° (115 mins., constant value). The product was isolated in the usual manner and was recrystallised from ether, giving 2-monomethyl xylose, m. p. 131°, $[\alpha]_D^{20°}$ + 34° in water (*c*, 0·9) (Found : OMe, 21·1. Calc. for $C_6H_{12}O_5$: OMe, 18·9%). The identity of the sugar was confirmed by comparing it with a sample of 2-monomethyl xylose prepared by Robertson and Speedie's method (J., 1934, 825). This had m. p. 133°, $[\alpha]_D^{20°}$ + 34° in water (*c*, 2·2), and a mixed m. p. gave no depression.

This series of experiments showed that the hydrolysis products from methylated xylan A consisted of 2 : 3-dimethyl methylxyloside (85—90%), 2 : 3 : 5-trimethyl methylarabinoside (2% approx.), 2 : 3 : 4-trimethyl methylxyloside (4% approx.), and 2-monomethyl methylxyloside (6—10%). The whole of the arabinose had not been removed, but wherever it had been eliminated by the acid-treatment of the original xylan a terminal xylopyranose unit was found instead. Further experiments were then made in which the whole of the arabinose was removed without degradation of the xylan molecule. Oxalic acid was found to be a convenient reagent for this purpose.

Preparation of Arabinose-free Xylan.—Xylan (15 g.) was made into a paste with water (400 c.c.). Water (1600 c.c.) was added, and the mixture heated at 100° for 2 hours. Oxalic acid (4·5 g.) was then added and the heating was continued for a further 5 hours. At this stage the reducing power (Fehling's solution) indicated the formation of 8% by weight of arabinose and further heating in the presence of oxalic acid brought about no increase in the reducing power. The xylan was then isolated in the manner described above and the arabinose in the aqueous-alcoholic supernatant liquor was separated as the benzylphenylhydrazone (yield of arabinose-free xylan, 180 g. from 210 g. of xylan).

Methylation of Arabinose-free Xylan.—The methylations were conducted exactly as described above. The methylated derivative so prepared was submitted to fractional precipitation, giving :

Fraction.	Weight, g.	Ash, %.	$[\alpha]_D$ in $CHCl_3$.	Apparent *M.W.* (by viscosity).	OMe, %.*
1	0·65	7·5	—	—	38
2	13·4	5·4	—	—	38
3	39·8	1·9	−91°	44 units	38·3
4	15·5	0·2	−90	46	38·1

* Corrected for ash-content.

Hydrolysis of fraction (3) by 1·2% methyl-alcoholic hydrogen chloride at the boiling point produced a non-reducing syrup, which was fractionally distilled, giving ultimately the *following fractions* :

Fraction.	Weight, g.	$n_D^{18\cdot5}$.	Estimated content of trimethyl methylpentoside, g.	Estimated content of monomethyl methylpentoside, g.
A *	0·76	1·4430	0·71	—
B	1·08	1·4475	0·69	—
C	3·35	1·4515	1·26	—
D	30·77	1·4570	—	—
E	3·53	1·4585	—	0·35
F	0·79	1·4650	—	0·42
G	1·29	1·4720	—	1·20
			Totals 2·66	1·97

* Found : OMe, 58·9%. Still residue 0·84 g.

From these figures the calculated chain length is 18 units. Similar hydrolyses carried out on fractions (2) and (4) gave almost identical results.

Identification of Hydrolysis Products.—(1) A portion of fractions (A) and (B) (mixed together) was hydrolysed with N/15-hydrochloric acid at 100°, the reaction being followed polarimetrically : $[\alpha]_D^{21°}$ + 14° (initial value); + 17° (30 mins.); + 19° (60 mins.); + 20° (150 mins., constant value). The final equilibrium value was not altered when the strength of the acid was increased to N and the heating continued for a further period (340 minutes). The solution was neutralised and the product isolated in the usual way, giving crystalline 2 : 3 : 4-trimethyl xylose, m. p. 89° alone or when mixed with an authentic sample, $[\alpha]_D^{22°}$ + 17°, equilibrium value in water (Found : OMe, 49·8. Calc. for $C_8H_{16}O_5$: OMe, 48·4%) (yield, 30% of the theoretical). The low yield was caused by difficulties during crystallisation due to contamination with 2 : 3-dimethyl xylose.

(2) The 2 : 3-dimethyl methylxyloside was identified, as before, by its conversion into 2 : 3-dimethyl xylonamide, m. p. 133°. In addition a portion of it was methylated, giving 2 : 3 : 4-trimethyl methylxyloside (yield, quantitative), and the latter substance was hydrolysed to 2 : 3 : 4-trimethyl xylose, m. p. 90° (yield, 90% of the theoretical).

(3) From fraction (G) after hydrolysis with N-hydrochloric acid at 100° crystalline 2-monomethyl xylose, m. p. 131°, was isolated (yield, 80% of the theoretical) (Found: C, 44·3; H, 7·4; OMe, 21·0. Calc. for $C_6H_{12}O_5$: C, 43·9; H, 7·3; OMe, 18·9%).

Reducing Power of Xylan, Xylan A, and Arabinose-free Xylan.—It is shown above that the apparent molecular weight (by viscosity methods) of methylated arabinose-free xylan is approximately half that of ordinary methylated xylan. The figures in Table I show that the decrease in viscosity is accompanied by increase in reducing power. In each case cited, however, the chemical chain-length determined by the end-group method is the same, namely, 18 units approximately. The iodine number is the no. of c.c. of N/10-iodine required by 1 g. of substance, and the copper number (determined by the method of Knecht and Thomson, *J. Soc. Dyers and Col.*, 1920, **36**, 255) is the number of g. of copper reduced by 100 g. of substance.

TABLE I.

Substance.	Copper No.	Iodine No.	Apparent chain length estimated by: Iodine No.	Viscosity of Me derivative.	End-group assay of Me derivative.
Original xylan	0·37	1·67	91	92	18—19
Xylan after treatment with dilute HNO_3 (xylan A)	0·50	1·98	77	88	18—20
Arabinose-free xylan (oxalic acid treatment)	0·71	2·75	55	44	18—19

These viscosity data are not employed in any other than a comparative sense inasmuch as the factor used in their calculation may not be applicable to xylan. It is by coincidence perhaps that the apparent chain length is similar to that given by the iodine number.

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419. *2-Ketoquinuclidine and a New Synthesis of Quinuclidine.**

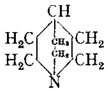
By G. R. Clemo and T. P. Metcalfe.

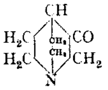
2-Ketoquinuclidine (II) has been prepared through the Dieckmann condensation of *ethyl piperidine*-1-*acetate*-4-*carboxylate*. Reduction by both the Wolff and the Clemmensen method gives quinuclidine (I).

Although the quinuclidine ring system only occurs naturally in the cinchona alkaloids, it is nevertheless of much interest. Quinuclidine (I) was first prepared by Löffler and Stietzel (*Ber.*, 1909, **42**, 124), who employed the same series of reactions previously used by Koenigs and Bernhardt (*Ber.*, 1904, **37**, 3244; 1905, **38**, 3049) for the preparation of 2-ethylquinuclidine from 4-methyl-3-ethylpyridine: γ-picoline was condensed with formaldehyde, and the resulting β-4-pyridylethyl alcohol reduced with sodium and alcohol; treatment of the product with hydriodic acid gave β-4-piperidylethyl iodide, which underwent an intramolecular rearrangement to quinuclidine hydriodide, the yield in the last process being only 10%.

Meisenheimer (*Annalen*, 1920, **420**, 190) repeated this synthesis; he increased the yield in the intramolecular rearrangement to 70% and described the base as a volatile crystalline solid with the surprisingly high m. p. 158°, whereas Löffler and Stietzel had described it as a liquid, b. p. 141°, and 2-ethylquinuclidine, according to Koenigs and Bernhardt, has b. p. 190°/720 mm.

In the preparation of quinuclidine, the rather inaccessible γ-picoline, obtainable from commercial β-picoline by fractional crystallisation of the mercuric chloride double salts, was employed and furthermore, the yield from the condensation with formaldehyde to give 4-pyridylethyl alcohol was very poor, being only about 1% in Meisenheimer's work. It is not surprising, therefore, that the chemistry of (I) has been little investigated.

(I.) 

 (II.)

A much better method for the preparation of quinuclidine has now been found. Ethyl piperidine-4-carboxylate (this vol., p. 1523) was condensed with ethyl chloroacetate to give *ethyl piperidine*-1-*acetate*-4-*carboxylate* and the Dieckmann reaction, followed by hydrolysis and decarboxylation, gave 2-*ketoquinuclidine* (II) as a crystalline deliquescent solid.

The Clemmensen and the Wolff reduction of this ketone were of special interest [the ketone being comparable with 1-keto-octahydropyridocoline, from which octahydropyridocoline and *nor*lupinane have been obtained by these two reduction methods (J., 1936, 1429)], but, as anticipated, quinuclidine, which theoretically can only exist in one form, was obtained in each case. Further work on 2-ketoquinuclidine is in progress.

Experimental.

Ethyl Piperidine-1-*acetate*-4-*carboxylate*.—Ethyl piperidine-4-carboxylate (8·2 g.), ethyl chloroacetate (8 g.), and anhydrous potassium carbonate (8 g.) were mixed and heated at 110—115° for 4 hours. Water was added, and the *oil* taken up in ether and fractionated (9·35 g., b. p. 134—136°/1 mm.) (Found: C, 58·8; H, 8·8. $C_{12}H_{21}O_4N$ requires C, 59·2; H, 8·7%).

2-Ketoquinuclidine.—The above di-ester (4·4 c.c.) in toluene (5 c.c.) was added to a warm suspension of very finely powdered potassium (2 g.) in toluene (8 c.c.); the mixture, heated

* This paper was written some time before the *Annalen*, 1937, **32**, came to hand with the description (p. 69) by Prelog of a synthesis of quinuclidine by a modification of the method he used for *bicyclo*[1 : 2 : 2]aza-1-heptane (*Annalen*, 1936, **525**, 292).

at 120° for 10 minutes, solidified, and was then heated at 110° for 3 hours. After cooling, alcohol was added to remove the excess of potassium, followed by water (2 c.c.) and concentrated hydrochloric acid (50 c.c.), and the solution was heated in the water-bath for 14 hours. After evaporation to dryness, the residue was basified with potassium hydroxide solution (50%), and the product extracted with ether. The pale yellow extract, dried over potassium carbonate, was added to a warm alcoholic solution of picric acid (3 g.). The ketone picrate which separated (2·2 g., m. p. 188—190°), after one crystallisation from alcohol, was decomposed with a slight excess of potassium hydroxide solution. The product, extracted and dried (solid potassium hydroxide) in ether, gave on distillation the *ketone* (1 g., b. p. 110°/12 mm.) as a colourless crystalline solid. It readily sublimed in a vacuum (1 mm.) in colourless deliquescent prisms, was easily soluble in light petroleum (b. p. 60—80°) at the ordinary temperature and separated at 0° in colourless dendrites, m. p. 138° (Found: C, 67·1; H, 9·3. $C_7H_{11}ON$ requires C, 67·2; H, 8·9%). The *methiodide*, formed in acetone, crystallised from alcohol in colourless prisms, m. p. 310° (decomp.) (Found: C, 36·0; H, 5·9. $C_8H_{14}ONI$ requires C, 35·95; H, 5·2%). The *picrate* was difficultly soluble in alcohol and crystallised from alcohol–acetone in golden-yellow rectangular prisms, m. p. 210° (Found: C, 44·0, 44·1; H, 3·75, 4·2. $C_7H_{11}ON,C_6H_3O_7N_3$ requires C, 44·1; H, 4·0%).

Quinuclidine.—(1) *Wolff reduction.* The ketone (0·3 g.), regenerated from 1 g. of its picrate, and hydrazine hydrate (0·5 g. of 95%) were refluxed for 24 hours, the hydrazone extracted with ether, the extract dried over sodium sulphate, and the ether removed. The residual viscous liquid (0·35 g.), sodium ethoxide (from sodium, 0·2 g.), and alcohol (4 c.c.) were heated in a sealed tube at 175° for 5 hours. Water was added, followed by excess of hydrochloric acid, and the solution was evaporated to dryness. The residue was basified, the base extracted with ether, and the dried extract added to an alcoholic solution of picric acid (0·2 g.); 0·2 g. of a picrate, m. p. 270°, separated at once. The picrate formed rosettes of bright yellow, acicular prisms, m. p. 275° (decomp.), from alcohol; Meisenheimer gives m. p. 275—276° (Found: C, 45·5; H, 4·9. Calc. for $C_7H_{13}N,C_6H_3O_7N_3$: C, 45·9; H, 4·7%).

(2) *Clemmensen reduction.* The ketone (0·3 g.) was refluxed for 24 hours with amalgamated zinc (10 g.) and concentrated hydrochloric acid (15 c.c.). More amalgamated zinc (5 g.) and hydrochloric acid (10 c.c.) were then added and the refluxing was continued for a further 20 hours. The acid solution was decanted, basified with concentrated sodium hydroxide solution, and steam-distilled until the distillate was no longer alkaline to litmus (about 100 c.c.). It was then acidified with hydrochloric acid and taken to dryness, the residue basified with potassium hydroxide solution (50%) and thoroughly extracted with ether, and the extract dried over potassium carbonate and added to an alcoholic solution of picric acid (0·3 g.); 0·25 g. of a picrate separated at once (m. p. 250° approx.). One recrystallisation from alcohol raised the m. p. to 268—270° (decomp.) and a second gave yellow prisms, m. p. 275° (decomp.), identical with the picrate obtained in the Wolff reduction.

The above picrate (0·5 g.) was decomposed by grinding with dilute hydrochloric acid (1 : 1), the filtered solution taken to dryness, and the residue basified with potassium hydroxide solution (50%) and thoroughly extracted with ether. The extract was dried over potassium carbonate and then solid potassium hydroxide and distilled in a vacuum over the latter reagent, the receiver being cooled in solid carbon dioxide. The quinuclidine was thus obtained in colourless prisms; on recrystallisation from light petroleum (b. p. 40—50°) at 0° it formed dendrites which sublimed so easily in a sealed tube that its accurate melting point has not been found. It gave the ethiodide in colourless prisms, m. p. 270° as claimed by Meisenheimer.

One of us thanks the Department of Industrial and Scientific Research for a grant and our thanks are due to the Medical Research Council for a grant for materials and to Mr. W. A. Campbell for microanalyses.

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420. *Experiments on the Combination of Nitrogen Peroxide and Nitric Oxide in the Absence of Moisture.*

By David L. Chapman and Muriel C. C. Chapman.

Experiments have been made to determine whether the combination of nitric oxide with nitrogen peroxide to form dinitrogen trioxide is affected by prolonged drying. It was found that the carefully dried gases combined and condensed to a blue liquid as easily as the partly dried gases in a control tube.

Experiments by H. B. Baker and Mrs. Baker (J., 1907, **91**, 1862; 1912, **101**, 2339) on dinitrogen trioxide appeared to demonstrate the catalytic effect of minute quantities of water vapour on its dissociation. The carefully desiccated liquid had a molecular weight (determined cryoscopically in benzene) of about 83, and determinations of the density of the vapour gave values varying from 38, corresponding to N_2O_3, to 62, a value which indicated a considerable proportion of N_4O_6. The vapour density given by one specimen of incompletely dry trioxide was about 28, in fair agreement with the results of earlier investigators. Further, the dried liquid showed a very marked rise in boiling point.

If, however, the reactions $N_4O_6 \longrightarrow 2N_2O_3$ and $N_2O_3 \longrightarrow NO_2 + NO$ are catalysed by water vapour, the converse reactions also should be catalysed, and we should expect to find that a dried mixture of equal volumes of nitrogen peroxide and nitric oxide would exhibit greater reluctance to combine and condense to a blue liquid than a moist mixture of the same composition. In order to investigate this the following experiments were carried out.

Experimental.

In some preliminary experiments in which the vapour of dinitrogen trioxide was sealed up in a tube with phosphoric oxide, it was observed that the brown colour of the gas gradually diminished in intensity, and that after a time the gas could not be condensed to a liquid by means of a freezing mixture of ice and salt; but on the cause of this effect being investigated, it was established that the phosphoric oxide absorbs the peroxide of nitrogen—gradually at the temperature of the laboratory, and rapidly at a higher temperature. Therefore, in all further experiments the phosphoric oxide was distilled into the experimental tube in the current of dinitrogen trioxide vapour, it being thereby ensured that the distillate would be saturated with nitrogen peroxide at the partial pressure of that gas in the mixture it was required to desiccate.

The trioxide was prepared by gently heating a mixture of arsenic trioxide and nitric acid. Most of the moisture was removed from the dissociated vapour by condensation in a reflux condenser, and the gas was dried by passing it through a long tube filled with phosphoric oxide. The dried vapour was condensed in a U-tube surrounded by a freezing mixture of ice and salt. The U-tube was connected with the Jena-glass tube, which it was required to fill with the dissociated trioxide, by means of a ground glass joint. The Jena-glass tube was constricted at a distance of about 15 cm. from the ground glass joint, and was bent at right angles at about 10 cm. from the constriction. It terminated in a capillary tube. A tube filled with fused calcium chloride was fitted on to the capillary end of the Jena tube to prevent the entrance of atmospheric moisture. Between the ground glass joint and the constriction of the Jena-glass tube several plugs of phosphoric oxide were introduced. Connections were made with ground glass joints lubricated with glacial phosphoric acid.

The filling of the tube was accomplished in the following manner. The freezing mixture surrounding the tube which contained the recently condensed trioxide was removed, and the temperature of the liquid trioxide was raised sufficiently to give a steady stream of gas. The phosphoric oxide in the Jena-glass tube was then heated with the naked flame, the constriction at the same time being kept at a moderately high temperature. The phosphoric oxide melted to a perfectly transparent liquid,* and easily distilled through the constriction into the front compartment of the tube between the constriction and the bend. Care was taken that its temperature should not rise too high during the distillation; this was to avoid contamination

* Phosphoric oxide which is incompletely oxidised melts to a dark grey liquid. It was shown in separate experiments that the oxide which had been distilled in the oxides of nitrogen contained no lower oxides of phosphorus and was not contaminated with carbon.

of the distillate with metaphosphoric acid. After the phosphoric oxide had been distilled, the tube was allowed to cool with a slow current of the vapour passing through it, and it was then sealed before the blow-pipe at the constriction and at the terminal capillary tube. A similarly constructed control tube, which did not contain phosphoric oxide, was filled in the same manner from a corresponding middle fraction of the liquid and sealed in the same way.

The comparison of the properties of the dried vapour with those of the moist vapour was made in various ways. The tube containing the dried mixture and the control tube were placed symmetrically side by side in a freezing mixture so that the capillary tubes and the limbs of the wider tubes to which these were joined were surrounded by the freezing mixture, and the time required for condensation of a drop of the blue liquid was observed. It was the same in both cases and the colours of the liquids were identical. Also the maximum amounts of liquid condensed at the temperature of the freezing mixture were compared and found to be practically the same. When the tubes were removed from the freezing mixture, evaporation of the two specimens of liquid took place at the same rate, and the same changes in colour were observed in the liquids as they disappeared. The specimens of liquid obtained by immersing the tubes in a bath at 5° were green and of equal volume.

The comparison was made with mixtures which had been left in contact with phosphoric oxide for periods varying from 2 days to 2 years. Heating the tube which contained the dried gas and phosphoric oxide even to a temperature at which this oxide melted made no difference to the results obtained.

We can only conclude from these results that there is no difference between the properties of the very dry and the partly dried gas. It might be objected that the absorption of the gas by the phosphoric oxide reduces the efficiency of the latter as a drying agent, but we could detect no alteration in its appearance and hygroscopic character.

These experiments, therefore, as far as they go, fail to support the conclusions drawn from the Bakers' work on dinitrogen trioxide, and we think those results require further consideration. It should be noted that Baker himself observed that the colour of the vapour of the desiccated trioxide could not be distinguished from the colour of the mixed products of dissociation.

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421. *The Dipole Moments of Vapours. Part VI. Bond Moments and Mesomeric Moments.*

By L. G. Groves and S. Sugden.

An approximate method has been worked out for calculating the induced dipoles produced in the non-polar parts of a molecule by induction from a primary dipole. This method, which is a development of that suggested by Frank (*Proc. Roy. Soc.*, 1935, *A*, **152**, 171), allows for the rapid variation of electric field in the neighbourhood of the dipole.

When these induced moments are allowed for, fairly consistent bond moments for polar groups can be obtained from the data for aliphatic compounds. When these bond moments are used to compute the moments of aromatic compounds, it is found that in these substances additional moments are present which are identified as the mesomeric moments which correspond with the permanent electronic displacements postulated in the general electronic theories of organic reactions.

The directions of the mesomeric moments obtained from the dipole observations are in agreement with those deduced from organic reactions. In general, aromatic compounds containing ortho-para-directing groups exhibit large mesomeric moments whilst those containing meta-directing groups possess much smaller mesomeric moments.

In Parts I—V of this series we have recorded measurements of the dipole moments of 53 substances in the vapour state. These, together with other observations in the literature,

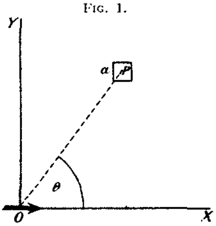
provide a considerable mass of data which are not subject to error due to solvent effect. In the present paper an attempt is made to analyse the observed moments in terms of bond moments and, in the case of aromatic compounds, to obtain information concerning the magnitude and direction of the mesomeric moments.

The chief difficulties encountered in such an analysis are connected with (*a*) valency angles and (*b*) induction within the molecule. Many attempts have been made to determine valency angles by the combination of suitable measurements of dipole moments (usually in solution) but such computations are beset with many sources of error. Wherever possible we have used the values of valency angles given by the analysis of band spectra, or *X*-ray or electron diffraction, as these methods in our opinion give more accurate values.

Sutton (*Proc. Roy. Soc.*, 1931, *A*, **133**, 668) has already discussed the dipole-moment evidence for the existence and direction of mesomeric moments. He used dipole moments determined in solution, and to allow for the induction, compared (when possible) *tert.*-butyl compounds with aromatic compounds. The following discussion deals only with dipole moments in the vapour state, and an attempt has been made to deal with induction quantitatively. Our general conclusions agree qualitatively with those of Sutton, but we believe that we have obtained a closer estimate of the magnitude of the mesomeric moments.

The calculation of induction within the molecule can only be carried out approximately, but by using a method of graphical integration suggested by Frank (*Proc. Roy. Soc.*, 1935, *A*, **152**, 171), the magnitude and direction of the induced moments can be computed with sufficient accuracy. It is, of course, necessary to adopt some simplified model of a molecule in order to make the problem amenable to calculation. Two such models have been used elsewhere. Smyth and McAlpine (*J. Chem. Physics*, 1933, **1**, 190) calculated the induction in each bond and obtained the bond polarisabilities in terms of bond refractions. Smallwood and Herzfeld (*J. Amer. Chem. Soc.*, 1930, **52**, 1919) regard each atom or group as a sphere of uniform polarisability and calculate the induced moment by assuming that this sphere is subjected to a field which is that produced at the centre of the sphere by the primary dipole. This model is sufficiently accurate when the atom or group is several A. distant from the primary dipole, for the field is then nearly constant over the volume of the atom considered. When the atom is near the primary dipole, the field is no longer approximately uniform, and some allowance must be made for the change in the field over the volume of the atom. This can be done by means of the graphical integration suggested by Frank.

FIG. 1.



Let the primary dipole of moment μ be situated at the origin and directed along the X axis (Fig. 1). At a point P the fields in the X and the Y direction are given by

$$\left.\begin{aligned} E_x &= \mu(3\cos^2\theta - 1)/\varepsilon_0 r^3 \\ \text{and} \quad E_y &= \mu(3\sin\theta\cos\theta)/\varepsilon_0 r^3 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where $r = OP$ and ε_0 is the dielectric constant of the intervening medium.

The induced moment per unit volume, I, is equal to $E(\varepsilon - 1)/4\pi$, where ε is the dielectric constant of the atom at P. Hence, if δV is the volume of the atom, the induced moment in the OX direction is

$$\mu_{ix} = [\delta V(\varepsilon - 1)/4\pi][\mu(3\cos^2\theta - 1)/\varepsilon_0 r^3]$$

Now if R is the refraction of the atom

$$\frac{R}{N} = \frac{\varepsilon - 1}{\varepsilon + 2}\cdot\frac{M}{Nd} = \frac{\varepsilon - 1}{\varepsilon + 2}\cdot\delta V = \frac{4\pi\alpha}{3}, \text{ whence } \delta V = \frac{4\pi\alpha}{3}\cdot\frac{\varepsilon + 2}{\varepsilon - 1}$$

$$\left.\begin{aligned} \text{and} \quad \mu_{ix} &= \mu\alpha[(\varepsilon + 2)/3\varepsilon_0][(3\cos^2\theta - 1)/r^3] \\ \text{Similarly,} \quad \mu_{iy} &= \mu\alpha[(\varepsilon + 2)/3\varepsilon_0][3\sin\theta\cos\theta]/r^3 \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

If r is large, then equations (2) can be used to compute μ_{ix} and μ_{iy} in a manner similar to that of Smallwood and Herzfeld. If r is small, it is necessary to use the method of graphical integration. Consider, first, the X component. For a small square of side a at P, the volume of the ring produced by revolution of the square about the OX axis is $2\pi r a^2 \sin\theta$. If β is the polarisability per unit volume, the moment produced in this ring, in the OX direction, is

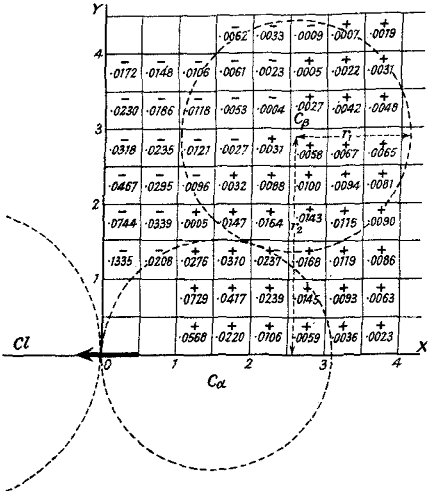
$$\mu_{ix} = [\mu(\varepsilon + 2)/3\varepsilon_0]\beta[a^2 2\pi r \sin\theta(3\cos^2\theta - 1)/r^3]$$

or

$$\mu_{ix}/\mu = \beta[(\varepsilon + 2)/3\varepsilon_0][2\pi \sin\theta(3\cos^2\theta - 1)a^2/r^2]$$

Now the quantity $A = \sin\theta\,(3\cos^2\theta - 1)a^2/r^2$ is dimensionless. Let it be computed for each of a number of small squares in the YOX quadrant, and the actual value of A

FIG. 2.



inserted in each such element of area. Now, choosing a suitable scale, draw on this diagram circles of diameter appropriate to the atoms concerned (Fig. 2 shows such a diagram with a scale sectional drawing for ethyl chloride superimposed). The primary dipole is assumed to be situated at the point of contact of the chlorine and the α-carbon atom, and the induced moment in the β-carbon is to be determined. Let ΣA_x be the sum of the values of A for the elementary squares and parts thereof included in the circle C_β. Then the induction in the anchor ring produced by revolution of this circle about the OX axis, $\mu_{ix}/\mu = [(\varepsilon + 2)/3\varepsilon_0]\beta \,.\, 2\pi \,.\, \Sigma A_x$. The volume of this ring is $\pi r_1^2 \,.\, 2\pi r_2$, and that of the C_β atom is $\frac{4}{3} \,.\, \pi r_1^3$. Hence, it being assumed that the induction in the sphere representing the C_β atom is to induction in the anchor ring in the ratio of their volumes, the induced moment in C_β in a direction parallel to the primary dipole is

$$\mu_{ix} = \mu\beta(4\pi r_1^3/3)[(\varepsilon + 2)/3\varepsilon_0]\Sigma A_x/\pi r_1^2 r_2$$

whence, since $\alpha = \beta \,.\, \frac{4}{3} \,.\, \pi r_1^3$,

$$\mu_{ix}/\mu = \alpha[(\varepsilon + 2)/3\varepsilon_0]\Sigma A_x/\pi r_1^2 r_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Similarly for the Y component we have (for the element of area a^2) a ring produced by revolution about the OY axis of volume $a^2 \,.\, 2\pi r \cos\theta$ and

$$\mu_{iy} = \mu \,.\, \beta \,.\, a^2 \,.\, 2\pi r \cos\theta \,.\, 3 \sin\theta \cos\theta(\epsilon + 2)/3\epsilon_0 r^3$$

or

$$\mu_{iy}/\mu = 2\pi\beta[(\epsilon + 2)/3\epsilon_0]\, 3 \sin\theta \cos^2\theta/(r^2/a^2)$$

Writing A_y for the dimensionless quantity $3 \sin\theta \cos^2\theta/(r^2/a^2)$, we can evaluate this for each unit of area on a second diagram, and following an identical procedure to that used in obtaining equation (3),

$$\mu_{iy}/\mu = \alpha[(\epsilon + 2)/3\epsilon_0]\Sigma A_y/\pi r_1{}^2 r_2 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

In this equation r_2 refers to the distance of the centre of the atom from the Y axis. The values of the constants in equations (3) and (4) now require consideration. Values of α for aliphatic compounds are readily obtained from the refractions, and those for the aromatic compounds are derived from the work of Stuart and Volkmann (*Ann. Physik*, 1933, **18**, 121):

Values of α, c.c. $\times 10^{-24}$.

Aliphatic.		Aromatic.
H 0·433	CH_2 1·82	CH (in plane of ring) 2·06
C 0·961	CH_3 2·25	
CH 1·39		C (atom 1 in phenyl radical) 1·63

Values for ϵ and ϵ_0 are less certain; little error is introduced, however, in assigning to these quantities 2·0 for aliphatic compounds and 2·4 for aromatic compounds.

Atomic radii, A.				Internuclear distances, A.			
C (al.)	0·77	N	0·70	C—Cl (al.)	1·76	C—O (al.)	1·43
C (ar.)	0·70	Cl	1·00	C—Cl (ar.)	1·69	C=O (al.)	1·28
H	0·32	Br	1·14	C—Br (al.)	1·93	C≡N	1·16
O	0·66	I	1·33	C—Br (ar.)	1·88		

In discussing induction within the molecule it is necessary to adopt some convention concerning the induction in the atoms which are joined by the bond in which the dipole is assumed to be situated. Thus, for example, in methyl chloride one might adopt the model of a primary dipole of negligible length situated between the carbon and the chlorine atom and then attempt to calculate the induction in the carbon and the chlorine atom. This induction would, however, be very large and would vary rapidly with changes in position of the dipole. It is indeed very doubtful whether the model of a dipole of negligible length is adequate to deal with this problem.

We have therefore adopted the convention of neglecting the induction in the atoms which are immediately adjacent to the dipole, and our "bond moments" therefore include the induction in these adjacent atoms. This convention is convenient since our main object was to determine such bond moments from aliphatic compounds and then, by comparison with appropriate aromatic compounds, to determine the sign and magnitude of the mesomeric moments.

Numerical Calculations.

Convention as to Sign of Moments.—Since we are mainly interested in determining whether the mesomeric moment is parallel or opposed to the primary moment, and since all the aromatic compounds considered have the negative end of the dipole remote from the ring, we have assigned positive values to such dipoles to avoid a multiplicity of minus signs in the calculations. This convention is, of course, the reverse of that used by Sutton (*loc. cit.*); to comply with his convention all the signs in Table II should be reversed.

(1) *Nitriles.—Acetonitrile.* The primary dipole C≡N is assumed to be midway between the nuclei, *i.e.*, 0·58 A. from the carbon nucleus. For the methyl carbon atom $\Sigma A_x = 0{\cdot}0661$. In this case, since the atom is on the dipole axis, revolution of the semicircle drawn on the diagram gives a sphere and hence the induction directly.

$$\mu_{ix}/\mu_{C\equiv N} = [(\epsilon + 2)/3\epsilon_0](\alpha/\tfrac{4}{3}\pi r_1{}^3) \,.\, 2\pi \,.\, \Sigma A_x = 0{\cdot}138$$

For each hydrogen atom $\Sigma A_x = 0{\cdot}0266$ and $r_2 = 1{\cdot}04$, hence

$$\mu_{ix}/\mu_{C\equiv N} = 0{\cdot}433 \times (4/6) \times 0{\cdot}0266/(6\pi \times 0{\cdot}32^2 \times 1{\cdot}04) = 0{\cdot}023_6$$

The Y components vanish by symmetry, and we therefore have the total induction parallel to the primary dipole and $\mu_{ix}/\mu = 0{\cdot}138 + (3 \times 0{\cdot}023) = 0{\cdot}207$. Hence

$$\mu_{CH_3 \cdot CN} = \mu_{CN} + \mu_{ix} = 1{\cdot}207\mu_{CN} = 3{\cdot}94,^* \; i.e., \; \mu_{C:N} = 3{\cdot}94/1{\cdot}207 = 3{\cdot}26.$$

In this calculation the shared electrons which hold the hydrogen atoms are assumed to be spread over the hydrogen sphere, whereas in fact they are largely located between the hydrogen and the carbon nuclei. A closer approximation to the true induction will probably be given by assigning the whole polarisability of the methyl group to the sphere representing the carbon atom. On this hypothesis $\mu_{ix}/\mu_{CN} = 2{\cdot}25 \times 0{\cdot}0661/0{\cdot}77^3 = 0{\cdot}326$, whence $\mu_{CN} = 3{\cdot}94/1{\cdot}326 = 2{\cdot}97$.

Propionitrile. For the CH_2 group, $\mu_{ix} = 0{\cdot}264\mu_{CN}$ and $\mu_{iy} = 0$. For the CH_3 group, $\mu_{ix} = 0{\cdot}067\mu_{CN}$ and $\mu_{iy} = 0{\cdot}074\mu_{CN}$. Hence the total moment $= \mu_{CN}(1{\cdot}331^2 + 0{\cdot}074^2)^{\frac{1}{2}} = 1{\cdot}333\mu_{CN}$; *i.e.*, $\mu_{CN} = 4{\cdot}04/1{\cdot}333 = 3{\cdot}03$. This is in good agreement with the value 2·97 calculated from acetonitrile. The moment of the C≡N dipole may therefore be taken as 3·00 ± 0·03. This differs little from the moment of hydrogen cyanide, *viz.*, 2·88.

Benzonitrile. μ_{iy} vanishes by symmetry, and we are left with μ_{ix} alone :

Atom	C_1	C_2 (× 2)	C_3 (× 2)	C_4	
μ_{ix}/μ_{CN}	0·246	0·126	0·052	0·017	Total = 0·441.

Hence assuming $\mu_{CN} = 3{\cdot}00$, $\mu_{calc.}$ for benzonitrile $= 1{\cdot}441 \times 3{\cdot}0 = 4{\cdot}32$; since $\mu_{obs.} = 4{\cdot}37$, the mesomeric moment is $+ 0{\cdot}05$. This is small, but is in the direction predicted by theory.

(2) *Halides.*—The primary moment μ is of necessity identified with the observed moment of the methyl derivatives.

Ethyl halides. For the β-carbon atom, $\Sigma A_x = 0{\cdot}076$ and $r_2 = 1{\cdot}47$. If we take $\alpha = 1{\cdot}82$—the value for CH_2—to allow for the hydrogen atom replaced in CH_3X, $\mu_{ix}/\mu = 0{\cdot}034$. $\Sigma A_y = 0{\cdot}4731$ and $r_2 = 1{\cdot}30$, whence $\mu_{iy}/\mu = 0{\cdot}237$ and the resultant moment $= (1{\cdot}034^2 + 0{\cdot}237^2)^{\frac{1}{2}}\mu = 1{\cdot}061\mu$.

*iso*Propyl halides. $\mu_{ix}/\mu = 2 \times 0{\cdot}034$ and $\mu_{iy}/\mu = 0{\cdot}237$, since this is the resultant of the Y components of the two methyl groups which are at 120° to one another. The resultant moment is given by $\mu_{calc.} = (1{\cdot}068^2 + 0{\cdot}237^2)^{\frac{1}{2}}\mu = 1{\cdot}094\mu$. Values of $\mu_{obs.}$ and $\mu_{calc.}$ for methyl, ethyl, and *iso*propyl halides are set out in Table I.

TABLE I.

X =	Cl.			Br.			I.		
	$\mu_{obs.}$	$\mu_{calc.}$	δ.	$\mu_{obs.}$	$\mu_{calc.}$	δ.	$\mu_{obs.}$	$\mu_{calc.}$	δ.
CH_3X	1·87	—	—	1·80	—	—	1·64	—	—
C_2H_5X	2·05	1·98	0·07	2·01	1·91	0·10	1·87	1·74	0·13
$Pr^{\beta}X$	2·15	2·05	0·10	2·19	1·97	0·12	—	—	—

It will be seen that the observed moments are all greater than those calculated and that the value of δ increases in the order Cl < Br < I. This effect is probably due to the field redistribution discussed in Part III.

Halogenobenzenes. For the five CH groups of the phenyl nucleus $\Sigma\mu_{ix}/\mu = 0{\cdot}433$, and the primary moments are taken as those of the methyl halides. Whence, we have :

Substance.	$\mu_{prim.}$	$\mu_{calc.}$	$\mu_{obs.}$	μ_{me}
Fluorobenzene	1·81 *	2·61	1·61 †	−1·00
Chlorobenzene	1·87	2·70	1·73	−0·97
Bromobenzene	1·80	2·60	1·71	−0·89
Iodobenzene	1·64	2·37	1·50 †	−0·87

* Values due to Smyth (*J. Chem. Physics*, 1933, **1**, 190).

† Obtained from values in benzene solution by multiplication by the factor $\mu_{vap.}/\mu_{sol.}$ for chlorobenzene.

The values of μ_{me}—the mesomeric moment—are all negative, indicating opposition to the primary moment and hence drift of negative charge into the ring.

(3) *Ethers.—Dimethyl ether.* In this ether the oxygen bond angle is 111° ± 4° (Ackermann and Mayer, *J. Chem. Physics*, 1936, **4**, 377; Sutton and Brockway, *J. Amer.*

* All moments are given in Debye units, *i.e.*, e.s.u. × 10^{-18}.

Chem. Soc., **1935**, **57**, 473). In accordance with the convention adopted for methyl halides, the primary C–O moment is assumed to be that of either CH_3–O link. It remains to calculate the moment induced in each methyl group by the more distant C–O dipole. From the appropriate diagrams $\mu_{ix} = 0{\cdot}058\mu_{CO}$ and $\mu_{iy} = 0{\cdot}393\mu_{CO}$, giving a resultant of $0{\cdot}398\mu_{CO}$ at an angle of 81·6° ($\tan^{-1} = 0{\cdot}393/0{\cdot}058$) to the OX axis or at an angle of 12·6° to the adjacent C–O bond. The moment of dimethyl ether is therefore obtained by compounding the moments shown in Fig. 3 :

$$\mu_{obs.} = 1{\cdot}28 = 2\mu_{CO}\cos 55{\cdot}5° - 2 \times 0{\cdot}398\mu_{CO}\cos 42{\cdot}9°$$

whence $$\mu_{CO} = 0{\cdot}64/(\cos 55{\cdot}5° - 0{\cdot}398\cos 42{\cdot}9°) = 2{\cdot}33.$$

Fig. 3.

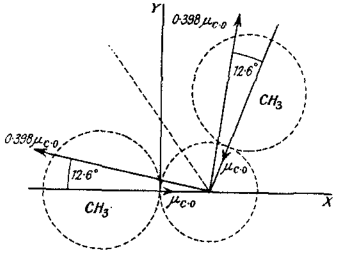
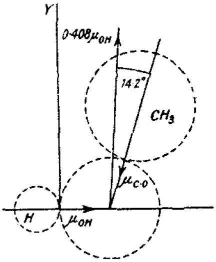


Fig. 4.



Water. For water $\mu_{obs.} = 1{\cdot}84$ and $\theta = 105°$ from band spectra data; hence $\mu_{OH} = 1{\cdot}51$.

Methyl alcohol. The oxygen angle being assumed to be 108°, intermediate between the values for water and dimethyl ether, we have only to consider the moment induced in the methyl group by the O–H dipole : $\mu_{ix} = 0{\cdot}027\mu_{OH}$ and $\mu_{iy} = 0{\cdot}408\mu_{OH}$, giving a resultant of $0{\cdot}408\mu_{OH}$ at 14·2° to the OMe link. The observed moment of methyl alcohol is thus made up of (1) a component parallel to the OMe link $= \mu_{CO} - 1{\cdot}51\cos 72° - 0{\cdot}408 \times 1{\cdot}51\cos 14{\cdot}2° = \mu_{CO} - 1{\cdot}065$, and (2) a component normal to the OMe link $= 1{\cdot}51\sin 72° - 0{\cdot}408 \times 1{\cdot}51\sin 14{\cdot}2° = 1{\cdot}288$ (see Fig. 4). Therefore $\mu_{obs.}^2 = 1{\cdot}69^2 = (\mu_{CO} - 1{\cdot}065)^2 + 1{\cdot}288^2$

or $$\mu_{CO} = 1{\cdot}065 \pm 1{\cdot}094 = 2{\cdot}16 \text{ or } -0{\cdot}03.$$

The latter value is inadmissible. Repeating the calculation with $\theta = 111°$ for both dimethyl ether and methyl alcohol, we have :

Substance.	Oxygen angle.	μ_{C-O}.	Substance.	Oxygen angle.	μ_{C-O}.
Dimethyl ether	111°	2·33	Methyl alcohol	111°	2·24
,, ,, ...	108		,, ,, ...	108	2·16

For use in subsequent calculations we shall adopt a value of $\mu_{C-O} = 2{\cdot}30$.

Diphenyl ether. From electron-diffraction measurements on 4 : 4′-di-iododiphenyl ether (Maxwell, Hendricks, and Mosley, *J. Chem. Physics*, 1935, **3**, 699), the oxygen valency angle is 118° ± 3°, and we shall assume this value in diphenyl ether. From results for halogenobenzenes, the induction in each phenyl radical adjacent to each C–O link is 0·433, parallel to the primary moment, but the induction in each phenyl radical due to the more distant C–O link must be calculated as in the case of dimethyl ether. The assumption will be made that the phenyl radicals and the C–O–C bonds are coplanar. Calculation gives a resultant moment of 1·068 at an angle of 78·3° to the OX axis, derived as follows :

	C_1.	C_2.	C_3.	C_4.	C_5.	C_6.	$\Sigma\mu_i$.
μ_{ix}	0·208	−0·135	−0·032	negl.	0·033	0·142	0·216
μ_{iy}	0·606	0·184	0·048	0·043	0·052	0·112	1·045

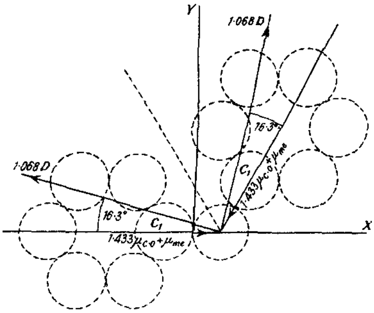
Since the oxygen angle is 118°, the induced moment is at an angle of 16·3° to the OPh link (Fig. 5). The observed moment is obtained by suitable compounding of primary and induced moments, the mesomeric moment being assumed to act along the O–C–Ph axis. Hence

$$\mu_{obs.} = 1{\cdot}35 = 2(2{\cdot}30 \times 1{\cdot}433 + \mu_{me}) \cos 59° - 2 \times 1{\cdot}068 \times \cos 42{\cdot}7°$$

i.e., $$1{\cdot}35/2 = 1{\cdot}700 + 0{\cdot}515\mu_{me} - 0{\cdot}785, \text{ or } \mu_{me} = -0{\cdot}47.$$

This is a fairly large moment and acts in opposition to the primary moment, as suggested by theory. It is observed that the assumption of coplanarity of rings and O–C–O bonds is substantially correct, for though the phenyl radicals are capable of free rotation, inspection of the table above shows that most of the induction occurs in carbon atom C_1. Little error will arise if free rotation be admitted but not allowed for.

FIG. 5.

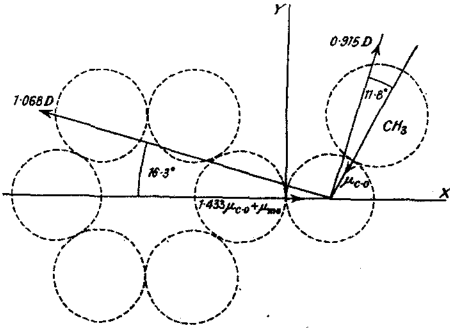


Anisole. The oxygen angle will be assumed equal to that in diphenyl ether, since the resonance which gives rise to the mesomeric moment will tend to increase the "double bond" character of the PhO link. The value of μ_{me} may be derived from constants obtained in the calculations for diphenyl ether, and from the moment induced in the methyl group by the OPh dipole. The latter is $0{\cdot}398\mu_{CO} = 0{\cdot}915$ at an angle of 73·8° to the *OX* axis or 11·8° to the OMe link. Resolving parallel and perpendicular to the OPh link (Fig. 6), we have:

$$\mu = 3{\cdot}30 + \mu_{me} - 2{\cdot}30 \cos 62° + 0{\cdot}915 \cos 73{\cdot}8° - 1{\cdot}068 \cos 16{\cdot}3° = \mu_{me} + 1{\cdot}45 \text{ (parallel)}$$

and $$\mu = 2{\cdot}30 \sin 62° - 0{\cdot}915 \sin 73{\cdot}8° - 1{\cdot}068 \sin 16{\cdot}3° = 0{\cdot}85 \text{ (perpendicular)}$$

FIG. 6.



Hence, $\mu_{obs.}^2 = 1{\cdot}35^2 = (\mu_{me} + 1{\cdot}45)^2 + 0{\cdot}85^2$ and $\mu_{me} = -1{\cdot}45 \pm 1{\cdot}048 = -0{\cdot}40$ or $-2{\cdot}50$.

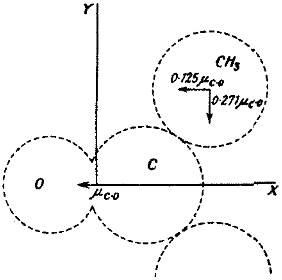
The larger value is improbable, but the smaller is comparable in magnitude and direction to that of diphenyl ether.

Phenol. A bond angle of 118° being assumed, the mesomeric moment may again be calculated from accumulated results. The moment induced in the phenyl group due to the O–H dipole is 0·70 (= 1·068 × 1·51/2·30) at 16·3° to the OPh link. The moments to be compounded are therefore $3·30 + \mu_{me} - 0·70 \times \cos 16·3° - 1·51 \cos 62° = \mu_{me} + 1·92$ (parallel) and $1·51 \sin 62° - 0·70 \sin 16·3° = 1·13$ (perpendicular). Hence, $\mu_{obs.}^2 = 1·40^2 = (\mu_{me} + 1·92)^2 + 1·13^2$ and $\mu_{me} = -1·12$ or $-2·74$.

Again the larger value is improbable, but it is interesting to note the sudden increase in magnitude shown by $-1·12$ as compared with approximately $-0·5$ in anisole and diphenyl ether.

(4) *Carbonyl Compounds.—Acetone.* The dipole here is assumed to be midway between the carbon and the oxygen nucleus, *i.e.*, 0·64 A. from the former, and the O=C⟋Me angle is taken as 125°; $\mu_{tx} = 0·125\mu_{C:O}$, so $\mu_{obs.} = 2·85 = \mu_{C:O} + 2\mu_{tx} = 1·25\mu_{C:O}$ (*Y* components vanish by symmetry) and $\mu_{C:O} = 2·28$ (Fig. 7).

FIG. 7.



Acetaldehyde. In this compound the value of μ_{iy}/μ for the methyl group must be considered. This is 0·271, so that, the hydrogen atom being neglected, the total moment is given by compounding $\mu_{C:O} + 0·125\mu_{C:O}$ parallel, and $0·271\mu_{C:O}$ perpendicular, to the C=O link; *i.e.*,

$$\mu_{obs.} = 2·68 = \mu_{C:O}(1·125^2 + 0·271^2)^{\frac{1}{2}} = 1·158\mu_{C:O}, \text{ or } \mu_{C:O} = 2·32.$$

If the induction in the hydrogen atom be included, for which $\mu_{tx}/\mu = 0·070$ and $\mu_{iy}/\mu = 0·103$, then we must compound $\mu_{C:O} + (0·125 + 0·070)\mu_{C:O}$ parallel, and $(0·271 - 0·103)\mu_{C:O}$ perpendicular, to the C=O link. Hence

$$2·68 = \mu_{C:O}(1·195^2 + 0·168^2)^{\frac{1}{2}} = 1·202\mu_{C:O} \text{ and } \mu_{C:O} = 2·23.$$

The mean of all three is 2·28, which is remarkably close to the value for μ_{O-O}, *viz.*, 2·30.

Acetophenone. The angle O=C⟋Ph being assumed to be 125°, the induced moments in the phenyl radical are as follows:

	C_1.	C_2.	C_3.	C_4.	C_5.	C_6.	$\Sigma\mu_i/\mu$.
μ_{ix}/μ	0·098	−0·044	−0·009	0·003	0·018	0·067	0·133
μ_{iy}/μ	0·199	0·073	0·023	0·017	0·020	0·041	0·373

The argument respecting the plane of the phenyl radical is the same as for diphenyl ether, and the mesomeric moment is assumed to act along the $C_{al.}$—$C_{ar.}$ axis of the ring. If we take $\mu_{C:O} = 2·28$, $\mu_{tx} = 0·31$, and $\mu_{iy} = 0·85$, then by the usual calculation

$$\mu_{obs.}^2 = 3·00^2 = (2·88 + \mu_{me} \cos 55°)^2 + (0·23 + \mu_{me} \sin 55°)^2 \text{ and } \mu_{me} = 0·17 \text{ or } -3·87.$$

The small positive value is of comparable magnitude with other meta-directing groups and indicates a drift of negative charge out of the ring.

(5) *Nitro-compounds.*—The moment of the nitro-group may be regarded as due to two moments, the larger one being between the nitrogen and the oxygen atoms. Because of resonance, this moment is symmetrically directed along the line of the N–C bond. The latter itself may possess a small moment, which, owing to electron loss from the nitrogen atom, will have its negative end directed towards the carbon atom. As a first approximation the moment of the nitro-group will be considered as a dipole situated at the periphery of the nitrogen atom.

Nitromethane. $\mu_{tx}/\mu = 0·284$ and $\mu_{obs.} = 3·54$, whence $\mu_{NO_2} = 3·54/1·284 = 2·76$.

Nitroethane. For the CH_2 group, $\mu_{i_x}/\mu = 0{\cdot}230$, and for the CH_3 group, $\mu_{i_x}/\mu = 0{\cdot}064$ and $\mu_{i_y}/\mu = 0{\cdot}062$. We thus have

$$\mu_{obs.} = 3{\cdot}58 = \mu_{NO_2}(1{\cdot}294^2 + 0{\cdot}062^2)^{\frac{1}{2}} \text{ or } \mu_{NO_2} = 2{\cdot}76.$$

This value agrees well with that of nitromethane.

Nitrobenzene. The induction in the phenyl radical is

Atom	C_1	C_2 (× 2)	C_3 (× 2)	C_4	
μ_{i_x}/μ	0·223	0·130	0·052	0·026	Total 0·431.

therefore $\mu_{obs.} = 4{\cdot}24 = \mu_{me} + 1{\cdot}431\mu_{NO_2}$, and $\mu_{me} = 0{\cdot}29$. This has the same sign as the primary moment and indicates electron drift from the ring as required by theory.

Table II.

Bond moments, D.		*Mesomeric moments*, D.	
$H_3C—F$	1·81	Fluorobenzene	−1·00
$H_3C—Cl$	1·87	Chlorobenzene	−0·97
$H_3C—Br$	1·80	Bromobenzene	−0·89
$H_3C—I$	1·64	Iodobenzene	−0·87
C—O	2·30	Diphenyl ether	−0·47
		(in each Ph group)	
		Anisole	−0·40
		Phenol	−1·12
C=O	2·28	Acetophenone	0·17
C≡N	3·00	Benzonitrile	0·05
NO_2	2·76	Nitrobenzene	0·29

The results of this investigation are summarised in Table II. It will be seen that all the *op*-directing groups give a large negative mesomeric moment whilst the three *m*-directing groups give a small value of opposite sign. The value for benzonitrile is indeed not larger than the uncertainties in the method of calculation. The general conception of mesomeric displacement is thus confirmed, but the interesting fact emerges that the permanent mesomeric displacement is much smaller for *m*- than for *op*-directing systems.

We are indebted to Dr. J. J. Fox, O.B.E., for giving us facilities for carrying out this work.

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Government Laboratory, Clement's Inn Passage, Strand. [*Received, November 2nd*, 1937.]

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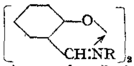
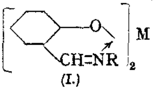
422. *Co-ordinated Copper and Nickel Compounds of Salicylidene Derivatives.*

By Louis Hunter and John A. Marriott.

Copper and nickel compounds of the type  M (where R = Ar, NHAr, NH·CO·NH_2) and also nickel salicylaldazine are described. Their solubilities and other properties are consistent with the co-ordination indicated in the formula. None of the copper derivatives offers any advantage over that of salicylaldoxime for the determination of copper.

Apart from the well-known metallic complexes derived from salicylaldoxime (Ephraim, *Ber.*, 1930, **63**, 1928; Brady, J., 1931, 105) no comprehensive study has been made of the tendency of compounds of formula (*o*)HO·C_6H_4·CH:NR to form chelate metallic salts. That this tendency is quite general is proved by the preparation and properties of copper and nickel complexes of general formula (I) derived from salicylidene-amines (R = aryl), -arylhydrazones (R = -NHAr), -semicarbazones (R = -NH·CO·NH_2), and -azines. None of the salts described offers any advantage over cupric salicylaldoxime as a means of gravimetric estimation of copper.



(I.)

The properties of the metallic derivatives described below leave no doubt as to their co-ordinated structure. They are crystalline substances, usually having a definite melting point, are decomposed by acid but stable to alkali, insoluble in water, sparingly soluble in alcohol but readily in benzene, nitrobenzene, chloroform, and pyridine. An important conclusion to be drawn from the general tendency of the salicylidene derivatives to form chelate metallic salts is that the configuration of the aryl groups about the –CH:N– is *trans*, for without this arrangement six-membered ring formation involving the metal is impossible. This conclusion is in harmony with the results of Hendricks, Wulf, Hilbert, and Liddel (*J. Amer. Chem. Soc.*, 1936, **58**, 1991), who, from the absence of bands typical of the hydroxyl group from the absorption spectra of salicylidene-aniline, -hydrazone, and -phenylhydrazone and salicylaldazine, deduce that the *o*-hydroxyl hydrogen is co-ordinated to nitrogen, necessarily implying a *trans*-configuration. Support for a chelated (and therefore a *trans*-) structure for the salicylidene-amines is also obtained from their superior solubility in organic solvents and their invariably lower melting points, as compared with the *m*- and *p*-isomers. Suppression of the usual associating function of the hydroxyl group was observed in salicylideneaniline, the molecular weight of which in benzene solution remained virtually normal over a considerable range of concentration.

Since its discovery by Ettling (*Annalen*, 1840, **35**, 241), the copper salt derived from hydrosalicylamide has been the subject of much discussion. By analogy with similar compounds, Delépine (*Bull. Soc. chim.*, 1899, **21**, 943) considered it to be derived from the unknown salicylaldimine, and this is now confirmed for both copper and nickel salts by molecular-weight determinations. The molecular weights of salts possessing a hydrosalicylamide structure would be almost three times those actually found.

By analogy with the metallic derivatives of the salicylidenediamines described by Pfeiffer and his co-workers (*Annalen*, 1933, **503**, 84; *J. pr. Chem.*, 1936, **145**, 243), double formulæ (*i.e.*, two metal atoms per molecule) have been ascribed to *nickel disalicylidene-benzidine* and *nickel salicylaldazine*.

EXPERIMENTAL.

(All temperatures are corrected.)

Two general methods are available for the preparation of the copper and nickel salts described below.

1. *By the action of metal acetate on the salicylidene derivative.* To the salicylidene derivative (2 mols.) in hot alcohol is slowly added a solution of the metal acetate (1 mol.) in 50% aqueous alcohol. The copper complexes are usually precipitated at once in a crystalline condition, but the nickel complexes frequently require the addition of alkali to neutralise the liberated acetic acid. This is best accomplished by adding slightly less than the theoretical amount of sodium hydroxide dissolved in alcohol; ammonia, especially in excess, must be avoided, as it leads to the formation of the metal derivative of salicylaldimine. After standing until the mixture is cold, the precipitated complex is filtered off and washed with water and alcohol; it is then usually pure enough for analysis.

2. *By the action of metal acetate on a mixture of salicylaldehyde and the amine or the hydrazine derivative.* To the amine or the hydrazine (2 mols., or 1 mol. of a diamine) in hot alcohol is added a hot alcoholic solution of salicylaldehyde (2 mols.), and a solution of the metal acetate (1 mol.) in 50% aqueous alcohol is added as before. If the salicylidene derivative is insoluble in alcohol, the salicylaldehyde may be added to a mixture of the amine and metal acetate; or the salicylaldehyde and metal acetate solutions may be added alternately, a few c.c. at a time, to the amine solution.

Estimation of the salicylidene residue. A convenient check on the composition of some of the metal complexes was provided by the estimation of the salicylidene residue ($-O\cdot C_6H_4\cdot CH=$, indicated in the subsequent analyses as "Sal."). This was performed gravimetrically by converting the salicylaldehyde obtained from them by the action of acid into salicylaldazine as follows. A weighed quantity (0·03—0·05 g.) of the metallic complex is decomposed by 50% sulphuric acid (25 c.c.), and the liberated salicylaldehyde driven over in steam into an alkaline solution of hydrazine. The operation is conveniently carried out in a micro-Kjeldahl distillation apparatus. The salicylaldazine is then precipitated by the addition of acid, and collected in a small (8 c.c.) sintered-glass crucible, washed with dilute

acid and water, and finally dried in a vacuum desiccator. Under these conditions the solubility of the azine is less than 1 mg./l., and the error due to this cause need not exceed 0·1 mg. of salicylaldazine (*i.e.*, about 0·2%). Weight of salicylidene residue = 0·875 × weight of azine.

The following compounds were obtained.

*Cupric salicylidene-*o*-toluidine*, dark brown, shining rhombic plates, m. p. 243—246° (decomp.) (Found: N, 5·9; Cu, 13·3. $C_{28}H_{24}O_2N_2Cu$ requires N, 5·8; Cu, 13·1%); m-*isomer*, brown rhombic plates with a red reflex, m. p. 188° (decomp.) (Found: N, 5·6; Cu, 13·1%); p-*isomer*, shining brown rhombic plates, m. p. 211—213° (decomp.) (Found: N, 5·8; Cu, 13·2%).

Cupric salicylidene-α-naphthylamine, small, brown, rectangular plates from chloroform, m. p. 259° (decomp.) (Found: N, 5·0; Cu, 11·6. $C_{34}H_{24}O_2N_2Cu$ requires N, 5·0; Cu, 11·4%); β-*compound*, thin, irregular, hexagonal plates from chloroform, m. p. 194—196° (Found: N, 5·0; Cu, 11·6%).

*Cupric salicylidene-*m*-chloroaniline*, microcrystalline, red-brown powder, m. p. 210—212° (decomp.) (Found: N, 5·2; Cu, 12·2. $C_{26}H_{18}O_2N_2Cl_2Cu$ requires N, 5·3; Cu, 12·1%); p-*compound*, chocolate-brown, microcrystalline powder, appearing as brown rhombic plates when precipitated from chloroform solution by addition of ether, m. p. 240° (Found: N, 5·4; Cu, 12·3%).

*Cupric salicylidene-*p*-bromoaniline*, red-brown, microcrystalline powder, appearing as golden-brown, rhombic plates when precipitated from chloroform solution by light petroleum; m. p. 250—251° (Found: N, 4·8; Cu, 10·3. $C_{26}H_{18}O_2N_2Br_2Cu$ requires N, 4·6; Cu, 10·4%).

*Cupric salicylidene-*m*-nitroaniline*, yellow, microcrystalline powder, m. p. 272° (decomp.) after blackening at 229° (Found: N, 10·2; Cu, 11·6. $C_{26}H_{18}O_6N_4Cu$ requires N, 10·3; Cu, 11·65%); p-*compound*, red-brown, microcrystalline powder, but clusters of needles when precipitated from pyridine by light petroleum; m. p. 313° (decomp.) after blackening at 308° (Found: N, 10·2; Cu, 11·8%).

*Cupric salicylidene-*o*-anisidine*, brown, microcrystalline powder, m. p. 222° (decomp.) (Found: N, 5·5; Cu, 12·6. $C_{28}H_{24}O_4N_2Cu$ requires N, 5·4; Cu, 12·3%); p-*compound*, red-brown, microcrystalline powder, m. p. 179° (decomp.) after blackening at 169° (Found: N, 5·6; Cu, 12·3%); when precipitated from chloroform solution by addition of ether, these compounds formed dark brown cubic crystals and rhombic plates, respectively.

Cupric salicylaldimine, prepared from hydrosalicylamide or from salicylaldehyde in the presence of ammonia, formed a green crystalline powder, m. p. 195° (decomp.) [Found: N, 9·2; Cu, 21·2; *M* (Rast), 290. $C_{14}H_{12}O_2N_2Cu$ requires N, 9·2; Cu, 20·9%; *M*, 304]; it appears to be identical with the copper " salicylimide " described by Ettling (*loc. cit.*).

Cupric salicylidenehydrazone, light brown powder, decomposing at 270—275° without melting (Found: Cu, 19·0; Sal., 63·8. $C_{14}H_{14}O_2N_4Cu$ requires Cu, 19·0; Sal., 63·0%); the corresponding *phenylhydrazone*, brown microcrystalline powder, m. p. 174° (Found: Cu, 13·3; Sal., 42·8. $C_{26}H_{22}O_2N_4Cu$ requires Cu, 13·1; Sal., 43·2%), when precipitated from chloroform solution by ether; and the p-*nitrophenylhydrazone*, microcrystalline brown powder, m. p. 221° (decomp.) (Found: Cu, 11·6. $C_{26}H_{20}O_6N_6Cu$ requires Cu, 11·3%).

Nickel salicylideneaniline, microcrystalline green powder, m. p. 248° (decomp.) (Found: N, 6·3; Ni, 12·9. $C_{26}H_{20}O_2N_2Ni$ requires N, 6·2; Ni, 13·0%); the corresponding derivatives of o-*toluidine*, green rhombic plates, m. p. 293° (decomp.) (Found: N, 5·9; Ni, 12·3. $C_{28}H_{24}O_2N_2Ni$ requires N, 5·9; Ni, 12·3%); m-*toluidine*, yellowish-green powder, appearing as small green rhombic plates when precipitated from chloroform solution by ether, m. p. 260° (Found: N, 5·8; Ni, 12·35%); p-*toluidine*, green octahedra from chloroform, m. p. 274° (decomp.) (Found: N, 5·7; Ni, 12·1%).

Nickel salicylidene-α-naphthylamine, green powder, m. p. 311° (decomp.) after blackening at 306° (Found: N, 5·2; Ni, 10·6. $C_{34}H_{24}O_2N_2Ni$ requires N, 5·1; Ni, 10·65%); β-*compound*, yellow powder, m. p. 220° after blackening at 206° (Found: N, 5·2; Ni, 10·4%); when precipitated from chloroform solution by addition of ether, these formed yellow needles and green rhombic plates, respectively.

*Nickel salicylidene-*o*-anisidine*, brown rhombic plates or rods, m. p. 319° (decomp.) (Found: N, 5·4; Ni, 11·3. $C_{28}H_{24}O_4N_2Ni$ requires N, 5·5; Ni, 11·5%). Nickel salicylaldimine, prepared from trisalicylidenediamine or from salicylaldehyde in the presence of ammonia, formed yellow rhombs with a golden reflex; when precipitated from dilute aqueous alcohol, the hydrate was obtained (Found: N, 8·9; Ni, 18·9. Calc. for $C_{14}H_{12}O_2N_2Ni,H_2O$: N, 8·9; Ni, 18·7%), but from acetone or from absolute alcohol the anhydrous complex, m. p. 335°

(decomp.) [Found : N, 9·2; Ni, 19·5; *M* (Rast), 308. Calc. for $C_{14}H_{13}O_3N_3Ni$: N, 9·3; Ni, 9·6%; *M*, 299], was obtained.

Nickel disalicylidenebenzidine, yellowish-green, microcrystalline powder, crystallising from pyridine in green rhombic plates, which do not melt or decompose below 360° (Found : N, 6·2; Ni, 12·9. $C_{52}H_{36}O_4N_4Ni_2$ requires N, 6·2; Ni, 13·1%).

Nickel salicylidenehydrazone, light brown powder, appearing as yellow microcrystals when precipitated from pyridine solution by alcohol; it decomposed without melting at 313° (Found : Ni, 17·4; Sal., 64·9 $C_{14}H_{14}O_2N_4Ni$ requires Ni, 17·8; Sal., 64·5%). *Phenylhydrazone* analogue, green rhombic plates from chloroform, decomposing indefinitely without melting at about 230° (Found : Ni, 12·0; Sal., 43·7. $C_{26}H_{22}O_2N_4Ni$ requires Ni, 12·2; Sal., 43·7%). *Nickel salicylaldazine*, light brown powder, stable without melting to 360° (Found : Ni, 19·5; Sal., 70·0. $C_{28}H_{20}O_4N_4Ni_2$ requires Ni, 19·8; Sal., 70·8%). *Nickel salicylidenesemicarbazone*, small, yellow, rhombic plates, decomposing at 302° (Found : Ni, 14·3; Sal., 50·9. $C_{16}H_{16}O_4N_6Ni$ requires Ni, 14·1; Sal., 50·6%).

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423. *The Configurations of Some* p-*Menthane Derivatives.*

By GEORGE H. KEATS.

The object of this work was to relate menthol and *iso*menthol, and the two geometrically isomeric 8-hydroxy-*p*-menthanes, to the *cis*- and the *trans*-form of *p*-menthane, of which they are derivatives. Electrolytic reduction of *l*-menthone gave *trans*-*p*-menthane, and *dl*-*iso*menthone yielded the *cis*-isomer, the configurations of the *p*-menthanes being based on a comparison of their physical properties with application of the Auwers–Skita rule. Hence *l*-menthol belongs to the *trans*-*p*-menthane series and *dl*-*iso*menthol to the *cis*-series. *l*-Menthol was converted into the bromide, which was dehalogenated by various methods to give *trans*-*p*-menthane. *dl*-*iso*Menthol, however, by a similar series of reactions, gave a mixture of *cis*- and *trans*-*p*-menthane. A somewhat analogous isomerisation was observed in the conversion of the 8-hydroxy-*p*-menthanes into *p*-menthane *via* the 8-chloro-*p*-menthanes, the *trans*-carbinol yielding *trans*-*p*-menthane, and the *cis*-isomer a mixture of the *cis*- and the *trans*-hydrocarbon.

IT is usually supposed that there is a *trans*-relationship between the methyl and the *iso*propyl group in menthone, whereas in *iso*menthone these groups occupy *cis*-positions. The evidence for this belief rests on a comparison of the physical properties of menthone and *iso*menthone. Zeitschel and Schmidt (*Ber.*, 1926, **59**, 2298) found that *d*-*iso*menthone has a slightly higher density and refractive index than *l*-menthone, and so, if these substances obey the Auwers–Skita rule (*Annalen*, 1915, **410**, 287; 1920, **420**, 91), the former is the *cis*-isomer. Again, Carter (J., 1927, 1278) has found that the parachors of menthones and *iso*menthones indicate a *cis*-configuration for the latter.

However, the small differences in the physical properties of menthone and *iso*menthone somewhat decrease the reliance to be placed on these deductions, and it was considered that, if menthol and *iso*menthol, or menthone and *iso*menthone, could be related to the two stereoisomeric forms of *p*-menthane, more definite evidence for the configurations of the former would be provided; for the Auwers–Skita rule could be applied with confidence to the *p*-menthanes, simple hydrocarbons differing considerably in physical properties.

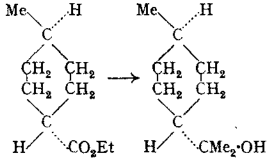
Schall and Kirst (*Z. Elektrochem.*, 1923, **29**, 537) found that menthone can be converted into *p*-menthane by electrolytic reduction at a cadmium cathode. On treating both *l*-menthone (II) and *dl*-*iso*menthone (VI) in this way, it was found that the *p*-menthane obtained from the latter had a considerably higher density ($d_{4^\circ}^{20^\circ}$ 0·8080) and refractive index ($n_D^{20^\circ}$ 1·4414) than that from the former ($d_{4^\circ}^{20^\circ}$ 0·7964, $n_D^{20^\circ}$ 1·4366). This clearly shows that menthone is derived from *trans*-*p*-menthane (III) and *iso*menthone from *cis*-*p*-menthane (VII). Since the ketones are made by the oxidation of *l*-menthol

(I) and *dl*-*iso*menthol (V), these substances also belong to the *trans*- and the *cis*-*p*-menthane series respectively.

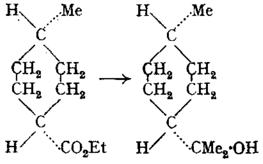
Attempts to convert *l*-menthol and *dl*-*iso*menthol into the stereoisomeric *p*-menthanes by means of other reactions proved difficult. Menthyl and *iso*menthyl chlorides were not suitable intermediates from which the *p*-menthanes could be obtained by dehalogenation, for *iso*menthyl chloride is not accessible. The action of phosphorus pentachloride on *dl*-*iso*menthol results in the formation of equal amounts of a chloride and an unsaturated oil, presumably a menthene mixture, and it is evident that the intermediate formation of Δ^3-*p*-menthene will destroy the *cis*-*trans* isomerism which the experiments are designed to preserve. Thionyl chloride was no more suitable than phosphorus pentachloride, as it caused dehydration of *l*-menthol. However, by replacing the hydroxyl group by bromine and reducing the resulting menthyl and *iso*menthyl bromides, *l*-menthol and *dl*-*iso*menthol have been found to yield *p*-menthanes of differing densities and refractive indices. *l*-Menthol yielded a *p*-menthane of $d_{4°}^{20°}$ 0·7970; $n_D^{20°}$ 1·4370 approx., whereas *dl*-*iso*menthol gave a product with $d_{4°}^{20°}$ 0·8020; $n_D^{20°}$ 1·4395 approx. The *p*-menthane derived from *l*-menthol consists almost entirely of the *trans*-form, and that from *dl*-*iso*menthol is a mixture of the *cis*- and the *trans*-form. In *iso*menthol, then, replacement of groups on carbon atom number 3 appears to produce partial inversion of the configuration of the groups on the neighbouring carbon atom. This inversion probably occurs during the formation of the halides and not during their reduction, since the composition of the *p*-menthane mixture remains approximately the same when different methods of reduction are used.

A somewhat similar phenomenon was observed when the two stereoisomeric 8-hydroxy-*p*-menthanes were converted into the 8-chloro-*p*-menthanes and these were reduced to the *p*-menthanes. The 8-hydroxy-*p*-menthane of m. p. 35° (IV), prepared from the ethyl ester of solid hexahydro-*p*-toluic acid as described by Perkin and Pickles (J., 1905, **87**, 650), yielded practically pure *trans*-*p*-menthane. The stereoisomeric 8-hydroxy-*p*-menthane of m. p. 25° (VIII), now for the first time prepared in the pure state by treating the ethyl ester of "liquid" hexahydro-*p*-toluic acid with methylmagnesium iodide, gave a mixture of *cis*- and *trans*-*p*-menthanes having $d_{4°}^{20°}$ 0·8017; $n_D^{20°}$ 1·4390. Experiments on the reduction of the 8-bromo-*p*-menthanes (obtained by the action of fuming hydrobromic acid on the 8-hydroxy-*p*-menthanes) gave unexpected results. Both bromo-compounds, when reduced by zinc dust in methyl alcohol, gave *trans*-*p*-menthane, whereas decomposition of the corresponding Grignard compounds derived from them gave a mixture of *cis*- and *trans*-*p*-menthane of the same composition in both cases. Here, then, the nature of the *p*-menthane produced depends on the method of debromination and is independent of the 8-hydroxy-*p*-menthane used as starting material.

In view of these complications, the evidence for the configurations of the 8-hydroxy-*p*-menthanes must be obtained mainly by a comparison of their physical properties and those of the hexahydro-*p*-toluic acids and esters from which they are derived.



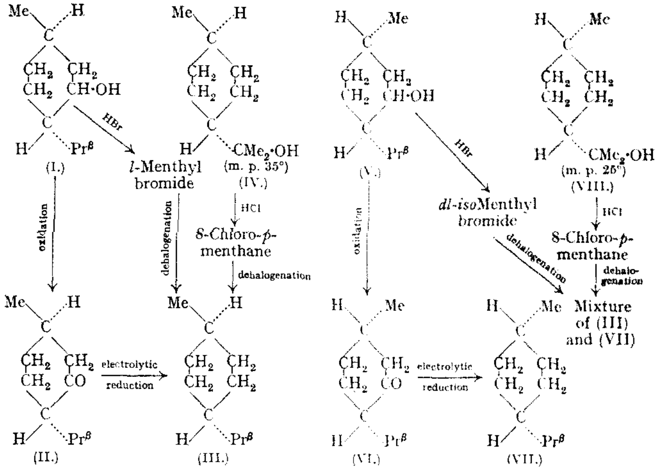
Ethyl ester of acid, m. p. 111°; $d_{4°}^{20°}$ 0·9361, n_D^{20} 1·4392. — 8-Hydroxy-*p*-menthane, m. p. 35°; $d_{4°}^{45°}$ 0·8962.



Ethyl ester of acid, m. p. 13°; $d_{4°}^{30°}$ 0·9448, $n_D^{20°}$ 1·4429. — 8-Hydroxy-*p*-menthane, m. p. 25°; $d_{4°}^{45°}$ 0·9025.

The above two pairs of geometrical isomers differ considerably in physical properties,

and the Auwers–Skita rule indicates that the substances of higher melting point are the *trans*-isomers.



Experimental.

The Electrolytic Reduction of l-*Menthone and* dl-iso*Menthone*.—The *l*-menthone and *dl*-*iso*menthone were made by the oxidation of natural *l*-menthol and of *dl*-*iso*menthol. The experimental conditions were as described by Schall and Kirst (*loc. cit.*) with slight modifications. The cathode consisted of pure sheet cadmium, the total area of metal immersed being 120 sq. cm.; the anode was of pure lead sheet. The anolyte, contained inside a porous pot, consisted of dilute sulphuric acid kept cool by a cooling coil. The catholyte was a mixture of 20 g. of *l*-menthone (or *dl*-*iso*menthone), 300 c.c. of ethyl alcohol, 70 c.c. of water, and 15 c.c. of concentrated sulphuric acid. The catholyte was stirred mechanically and was surrounded by a vessel of iced water. A current of 3—3·3 amps. was passed for 8 hours, and after 2 hours from the start 10 g. of menthone (or *iso*menthone) were gradually added to the catholyte. During the electrolysis the temperature of the catholyte remained between 10° and 15°, and at the end of the experiment the liquid had separated into two layers.

The *p*-menthane was isolated as described by Schall and Kirst, and purified as described below; yield 20 g., b. p. 167—168·5°.

The Action of Phosphorus Pentachloride on dl-iso*Menthol*.—60 G. of phosphorus pentachloride were covered with low-boiling petrol and cooled to 0°. 40 G. of *dl*-*iso*menthol were slowly added, and after 1 hour the mixture was poured on ice. The oil was washed with water and sodium hydroxide solution, dried over calcium chloride, and distilled under reduced pressure; yield, 16 g. of an unsaturated oil, b. p. 75—85°/18 mm., and 18 g. of a chloride, b. p. 97°/18 mm. 40 G. of *l*-menthol, treated in a similar way, gave 38 g. of menthyl chloride, b. p. 97°/18 mm.

The Action of Thionyl Chloride on l-*Menthol*.—20 G. of *l*-menthol were slowly added with shaking to 40 g. of thionyl chloride at 0°, and the mixture left for 2 hours, some hydrogen chloride being evolved during this period. The product was poured on ice and stirred well, and the oil was extracted with ether. The extract was washed with sodium hydroxide solution, dried over calcium chloride, and fractionated under reduced pressure; yield, 6 g. of menthene, b. p. 65—70°/15 mm., and 10 g. of unchanged menthol, b. p. 103—105°/15 mm.

The Preparation of l-*Menthyl and* dl-iso*Menthyl Bromide.*—These halides are best prepared by the action of fuming hydrobromic acid on the menthols. 20 G. of *l*-menthol or *dl-iso*-menthol were shaken in a pressure bottle with 100 c.c. of fuming hydrobromic acid, saturated at 0°. After 36 hours the oil was separated, washed with dilute sodium hydroxide solution, and fractionated under reduced pressure; yield, 15 g., b. p. 114°/22 mm.

*dl-iso*Menthyl bromide was also made by the following method. *dl-iso*Menthyl acetate was prepared by the action of acetyl chloride on *dl-iso*menthol, and was isolated as a pleasant-smelling liquid, b. p. 111°/20 mm., $d_{4^\circ}^{20^\circ}$ 0·9369. It was mixed with twice its volume of light petroleum (b. p. 60—80°), and the solution saturated with dry hydrogen bromide at − 10°; the reaction bottle was then stoppered and left for 4 days. The mixture was shaken with water, and the petroleum layer separated, shaken with sodium hydroxide solution, and dried over calcium chloride. It was fractionated under reduced pressure, and the portion, b. p. 116°/25 mm., collected; $d_{4^\circ}^{20^\circ}$ 1·130; the yield equalled the weight of *iso*menthyl acetate taken. *l*-Menthyl acetate is only partly converted into the bromide by this treatment. Estimations (by the Stepanow method) of the bromine contents of the above bromides gave values varying from 36·0% to 36·5% (Calc. for $C_{10}H_{19}Br$: Br, 36·5%).

The Dehalogenation of l-*Menthyl and* dl-iso*Menthyl Bromide.*—(a) The bromides were treated in glacial acetic acid solution with zinc dust (freed from oxide) with gentle warming and shaking. (b) The bromides were treated with magnesium in ether, and the resulting Grignard compounds were decomposed by iced water, followed by dilute acid (cf. Hesse, *Ber.*, 1906, **39**, 1132, 1151). (c) Solutions of the bromides in methyl alcohol (4 vols.) were shaken with zinc dust (3 parts) for a week at room temperature (cf. Harries and Stirm, *Ber.*, 1901, **34**, 1924).

In each case the *p*-menthane was isolated and purified as follows. The reduction product was extracted with ether, and the extract was washed, and dried over calcium chloride. After removal of the ether the residue was distilled, and the portion, b. p. 165—170°, was shaken with an equal volume of cold concentrated sulphuric acid for 15 minutes. This treatment removed any menthene, the acid becoming orange-coloured in the process. The *p*-menthane layer was separated, washed, and dried over calcium chloride. It was then twice distilled over sodium, and twice fractionated in a small flask with sealed-on glass Dufton column; b. p. 168°/760 mm. The physical properties of the *p*-menthanes after such treatment were not altered by further fractionation. The products contained no trace of halide, as shown by negative Beilstein and Lassaigne tests. Furthermore, refluxing with alcoholic potash, followed by re-isolation and purification, caused no change in physical properties.

Results: (1) 20 G. of menthyl bromide (from *l*-menthol and hydrobromic acid), reduced *via* the Grignard compound, gave 2 g. of *p*-menthane, $d_{4^\circ}^{20^\circ}$ 0·7971, $n_D^{20^\circ}$ 1·4373.

(2) 15 G. of menthyl bromide (from *l*-menthol and hydrobromic acid), reduced by zinc in methyl alcohol, gave 1·5 g. of *p*-menthane, $d_{4^\circ}^{20^\circ}$ 0·7973, $n_D^{20^\circ}$ 1·4367.

(3) 15 G. of *iso*menthyl bromide (from *dl-iso*menthol and hydrobromic acid), reduced *via* the Grignard compound, gave 2 g. of *p*-menthane, $d_{4^\circ}^{20^\circ}$ 0·8024, $n_D^{20^\circ}$ 1·4398.

(4) 10 G. of *iso*menthyl bromide (from *dl-iso*menthol and hydrobromic acid), reduced by zinc in methyl alcohol, gave 1·5 g. of *p*-menthane, $d_{4^\circ}^{20^\circ}$ 0·8020, $n_D^{20^\circ}$ 1·4390.

(5) 60 G. of *iso*menthyl bromide (from *dl-iso*menthyl acetate and hydrobromic acid), reduced *via* the Grignard compound or by zinc in acetic acid, gave 5·5 g. of *p*-menthane, $d_{4^\circ}^{20^\circ}$ 0·8022, $n_D^{20^\circ}$ 1·4396.

The Hydrogenation of p-*Toluic Acid.*—A solution of 10 g. of *p*-toluic acid in 60 c.c. of glacial acetic acid was shaken with hydrogen at atmospheric pressure in the presence of 0·5 g. of Adams's platinum oxide catalyst. The hydrogenation flask was kept warm by means of a steam jet, and with occasional aeration of the catalyst the reduction was complete in 4—5 hours, 3 mols. of hydrogen having been absorbed. The product was filtered, the acetic acid removed, and the residue fractionated under reduced pressure; yield, 8 g., b. p. 135°/20 mm. When kept in a freezing mixture, it slowly solidified to a mass of colourless needles, m. p. 13°. The ethyl ester of *p*-toluic acid was not hydrogenated so readily as the acid itself.

The ethyl esters of the two hexahydro-*p*-toluic acids, made by the Fischer–Speier method, were liquids, b. p. 97°/22 mm. A persistent and unpleasant smell was produced during their preparation.

The ethyl ester of hexahydro-*p*-toluic acid (m. p. 13°) had $d_{4^\circ}^{20^\circ}$ 0·9448, $d_{4^\circ}^{25^\circ}$ 0·9423, and $n_D^{20^\circ}$ 1·4429. The ethyl ester of hexahydro-*p*-toluic acid (m. p. 111°) had $d_{4^\circ}^{20^\circ}$ 0·9361, $d_{4^\circ}^{25^\circ}$ 0·9340, and $n_D^{20^\circ}$ 1·4392.

The Preparation of cis-*8-Hydroxy-*p-*menthane.*—This was made in good yield by the action of methylmagnesium iodide on the ethyl ester of the hexahydro-*p*-toluic acid of lower m. p., exactly as Perkin and Pickles (*loc. cit.*) made the *trans*-isomer from the ester of the acid of higher m. p. It was isolated by distillation under reduced pressure, and had b. p. 110°/30 mm.; it solidified to a mass of fine long needles, m. p. 25°. This carbinol had a fainter smell than its isomer of m. p. 35° and had $d_{4°}^{45°}$ 0·9025, whereas the *trans*-isomer had $d_{4°}^{45°}$ 0·8962 (Found: C, 76·8; H, 13·0. Calc. for $C_{10}H_{20}O$: C, 77·0; H, 12·8%). Its phenylurethane crystallised from light petroleum in clumps of short needles, m. p. 114°, depressed by the phenylurethane of the *trans*-carbinol, which crystallised from petroleum in long needles, m. p. 115°.

Zeitschel and Schmidt (*Ber.*, 1927, **60**, 1372) claimed to have isolated this *cis*-8-hydroxy-*p*-menthane from the mixture resulting from the hydrogenation of α-terpineol, but their product was an oil and so it cannot have been pure.

*The Preparation and Dehalogenation of the 8-Bromo-*p-*menthanes.*—18 G. of 8-hydroxy-*p*-menthane were shaken at room temperature for 2 days in a pressure bottle with 120 c.c. of hydrobromic acid (saturated at − 10°). The heavy oil was separated and extracted with ether, the extract washed and dried over calcium chloride, and the ether removed. The bromo-compounds were not distilled. Conversion into the Grignard compounds, followed by decomposition with water, gave approx. 1 g. of *p*-menthane. 8-Hydroxy-*p*-menthane (m. p. 25°) gave *p*-menthane, $d_{4°}^{20°}$ 0·8015, $n_D^{20°}$ 1·4384. 8-Hydroxy-*p*-menthane (m. p. 35°) gave *p*-menthane, $d_{4°}^{20°}$ 0·8015, $n_D^{20°}$ 1·4389.

Reduction of the bromo-compounds by zinc dust in methyl alcohol gave 1 g. of *p*-menthane having the following properties: 8-hydroxy-*p*-menthane (m. p. 25°) gave *p*-menthane, $d_{4°}^{20°}$ 0·7970, $n_D^{20°}$ 1·4370; 8-hydroxy-*p*-menthane (m. p. 35°) gave *p*-menthane, $d_{4°}^{20°}$ 0·7966, $n_D^{20°}$ 1·4366.

*The Preparation and Dehalogenation of the 8-Chloro-*p-*menthanes.*—The 8-hydroxy-*p*-menthanes were dissolved in 10 times their weight of dry ether saturated with dry hydrogen chloride at − 5°, and the solutions were left in pressure bottles at 0° for a day, and then at room temperature one day longer. The resulting chloro-compounds could be distilled under reduced pressure without decomposition; b. p. 59°/0·15 mm. (This method cannot be used for the preparation of menthyl chloride, since ethereal hydrogen chloride is without action on *l*-menthol.) The 8-chloro-*p*-menthanes were dehalogenated by decomposing the Grignard compounds with water. From 15 g. of 8-hydroxy-*p*-menthane, 3—4 g. of *p*-menthane were obtained: 8-hydroxy-*p*-menthane (m. p. 25°) gave *p*-menthane, $d_{4°}^{20°}$ 0·8017, $n_D^{20°}$ 1·4390; 8-hydroxy-*p*-menthane (m. p. 35°) gave *p*-menthane, $d_{4°}^{20°}$ 0·7970, $n_D^{20°}$ 1·4373.

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424. *Decomposition Reactions of the Aromatic Diazo-compounds. Part II. Some Reactions of Benzenediazonium Chloride.*

By WILLIAM A. WATERS.

The decomposition of solid benzenediazonium chloride under acetone, hexane, carbon tetrachloride, ethyl iodide, and ethyl acetate has been studied. Hydrogen chloride and chlorobenzene were the usual products, though with ethyl iodide some iodobenzene also was formed. The reaction under acetone kept neutral by chalk yielded benzene and chloroacetone.

Under acetone in presence of chalk benzenediazonium chloride attacked mercury, antimony, bismuth, lead, tin, nickel, iron, copper, and silver, giving the metallic chlorides. With mercury, phenylmercuric chloride also was produced, and with antimony triphenylstibine dichloride. The latter reaction affords a new method of synthesis of aromatic antimonials.

The theoretical aspects of the decomposition of benzenediazonium chloride are considered in detail and, in absence of water, it is suggested that the diazonium salt,

$(PhN_2)^+Cl^-$, first undergoes molecular rearrangement to diazobenzene chloride, Ph·N:NCl, which then decomposes, either by the spontaneous elimination of nitrogen with the production of the free neutral phenyl radical and atomic chlorine, *Ph· and Cl·, or, less probably, by a bimolecular decomposition* upon collision with another reagent.

The theoretical consideration of the alternative processes necessitates a discussion of the possible modes of reaction of all substances now regarded as containing "positive" or "electrophilic" halogen atoms, for example, dichloramine-T. It is not unfeasible that all such halogen compounds may react by undergoing a non-ionic fission of a covalent link, in consequence of which transient halogen atoms may be produced. Support for this new suggestion is drawn from the experimental fact that dichloramine-T, when dissolved in dry acetone, benzene, or carbon tetrachloride, was found to react with mercury.

Hitherto the mechanism of decomposition of diazonium salts has been considered chiefly in relation to reactions occurring in aqueous solution, from which no conclusive deductions can be made, for the decomposition might be either that of the diazonium kation or of a wholly covalent molecule. When, however, the decomposition of benzenediazonium chloride is studied in absence of water, other features of the process become apparent, and significant theoretical deductions may be drawn from the experimental evidence.

*Dry benzenediazonium chloride is explosive, but, although it is practically insoluble in solvents other than water, its decomposition under organic liquids can be regulated if one operates on a small scale, taking due precautions. The decomposition regularly seems to involve an interaction with the organic liquid—though whether this occurs prior or subsequent to the fission of the nitrogen is a moot point—and, from the nature of the mixtures of products which have been isolated by using liquids such as ethyl alcohol, acetone, and ethyl iodide (and others), it is evident that benzenediazonium chloride does not always behave in the way that would be anticipated of an ionic substance such as any other substituted ammonium halide.

It is well known that an alcohol can be oxidised during the decomposition of a diazonium salt,

$$PhN_2Cl + CH_3{\cdot}CH_2{\cdot}OH \longrightarrow PhH + CH_3{\cdot}CHO + HCl + N_2 \quad . \quad . \quad (A)$$

though, in general, an aryl ether is produced simultaneously :

$$PhN_2Cl + CH_3{\cdot}CH_2{\cdot}OH \longrightarrow Ph{\cdot}O{\cdot}C_2H_5 + HCl + N_2 \quad . \quad . \quad . \quad (B)$$

The oxidation of the alcohol (A), which is not a reaction one would anticipate of an ionised halide, has been ascribed to the initial formation of an alkyl hypochlorite (*e.g.*, $C_2H_5{\cdot}OCl$) (compare Hantzsch, *Ber.*, 1930, **63**, 1786), and this may well be the case, since with acetone a very similar reaction occurs,

$$PhN_2Cl + CH_3{\cdot}CO{\cdot}CH_3 \longrightarrow PhH + CH_2Cl{\cdot}CO{\cdot}CH_3 \quad . \quad . \quad . \quad (C)$$

which leads to the production of chloroacetone. By a concurrent reaction, however, a considerable quantity of hydrogen chloride is produced. Hydrogen chloride is also evolved in decompositions under ethyl acetate, hexane, and carbon tetrachloride. In the latter case, however, the sample of benzenediazonium chloride used may have contained a little moisture and the trace of water can have been the source of some of the hydrogen which combined with the chlorine.

Whenever hydrogen chloride was evolved during the reaction, chlorobenzene was found amongst the products, and, as in the decomposition of benzenediazonium chloride in concentrated hydrochloric acid (Hantzsch, *Ber.*, 1900, **33**, 2525), it may possibly have been formed by an interaction between undecomposed benzenediazonium chloride and molecular hydrogen chloride.

Under carbon tetrachloride the decomposition of benzenediazonium chloride gives a large yield (40%) of chlorobenzene. This may, to a great extent, be a product of a direct reaction between the diazonium salt and the carbon tetrachloride, for when another organic

halide, ethyl iodide, was used, both chlorobenzene and iodobenzene were found as products.

Benzenediazonium chloride under acetone, in presence of chalk, attacks silver, mercury, lead, antimony, bismuth, tin, copper, iron, and nickel, yielding metallic chlorides. Phenylmercuric chloride is produced in the reaction with mercury, and triphenylstibine dichloride in that with antimony. Both these reactions afford new methods of synthesis of aryl organo-metallic compounds.

The Mechanism of the Decomposition Process.—A decomposition process involving interaction with the organic liquid is in accord with the later theories of Hantzsch (*Ber.*, 1930, **63**, 1786), who pictured the reaction (A) between benzenediazonium chloride and ethyl alcohol as the decomposition of an addition product, Cl·NAr·NH·OEt, containing a covalent link between nitrogen and chlorine. He pointed out that chloride anions, such as would be present in the salt $(PhN_2)^+Cl^-$, never react with alcohols to yield alkyl hypochlorites, though compounds with covalent N–Cl links can do so. The same consideration applies to the reaction (C) between benzenediazonium chloride and acetone, for substituted ammonium chlorides are not chlorinating agents (compare Waters, *Nature*, 1937, **140**, 466) and do not interact with acetone, whereas compounds containing the N–Cl covalent link will chlorinate it (compare Behal and Detœuf, *Compt. rend.*, 1911, **153**, 1229). The reactions of benzenediazonium chloride with metals also do not accord with decompositions of diazonium salts, but do accord with possible decompositions of covalent chlorides.

However, though the inference that the reaction between benzenediazonium chloride and alcohol or acetone involves decomposition of a covalent chloride can be deduced in the manner set forth above, one need not suppose, with Hantzsch, that the diazonium chloride must form *addition* compounds which then decompose, for the diazonium salt itself might undergo a molecular rearrangement to give wholly covalent diazobenzene chloride :

$$(PhN_2)^+ Cl^- \longrightarrow Ph{\cdot}N{:}NCl \longrightarrow \text{reaction products}$$

Pray (*J. Physical Chem.*, 1926, **30**, 1477) has argued that it is not an addition compound between a diazonium salt and an alcohol which decomposes, for he found that the rate of decomposition of benzenediazonium chloride in various alcohols was independent of the nature of the alcohol, which would not be the case if the decomposing complex (see above) contained an alkyl group the identity of which could be varied at will. In the reaction with acetone one would scarcely have reason to suppose that a hydrazine derivative such as $NPhCl{\cdot}NH{\cdot}CH_2{\cdot}CO{\cdot}CH_3$ would be produced, or that such a compound would tend to decompose with elimination of nitrogen and formation of chloroacetone.

It is much simpler, therefore, to suppose that benzenediazonium chloride undergoes molecular rearrangement on warming to give an unstable diazobenzene chloride, of which the steric structure cannot as yet be specified, which decomposes either spontaneously or upon collision with another molecule. This theory is in accord with the fact that, in absence of metals, benzenediazonium chloride does not decompose under organic solvents below 50°. It can be heated under dry boiling diethyl ether without change, but under a number of other solvents it softens at 50—60° and a vigorous decomposition then sets in immediately.

In Part I (this vol., p. 113) evidence was brought forward to support the hypothesis that diazobenzene acetate, $Ph{\cdot}N{:}N{\cdot}O{\cdot}CO{\cdot}CH_3$, decomposes spontaneously into the free neutral radicals Ph· and $\cdot O{\cdot}CO{\cdot}CH_3$,* which then interact with vicinal solvent molecules. The spontaneous decomposition of covalent diazobenzene chloride into nitrogen and the free neutral phenyl radical and atomic chlorine can, with equal justification, be advanced to account for one stage in the decomposition reactions of benzenediazonium chloride mentioned above, since it will explain :

(i) The formation of benzene with alcohol and with acetone as :

$$Ph\cdot + HR \longrightarrow PhH + \cdot R$$

(ii) The formation of hydrogen chloride in all reactions :

$$Cl\cdot + HR \longrightarrow HCl + \cdot R$$

* A fine dot is used in this series of papers to denote an unshared electron.

(*iii*) The formation of chlorobenzene by any of the reactions:

$$Ph\cdot + \cdot Cl \longrightarrow PhCl$$
$$Ph\cdot + HCl \longrightarrow PhCl + \cdot H$$
$$Ph\cdot + CCl_4 \longrightarrow PhCl + \cdot CCl_3$$

(iv) The formation of iodobenzene from ethyl iodide.

(v) The chlorination of acetone: Neutral atomic chlorine is an electron-seeking ("elec-

$$Cl\cdot + CH_3\cdot CO\cdot CH_3 \longrightarrow CH_2Cl\cdot CO\cdot CH_3 + \cdot H$$

trophilic" or "kationoid") reagent, since it is deficient of its complete octet of electrons. It is therefore a chlorinating agent just as much as molecular chlorine, which may, in certain cases, act by fission to chlorine atoms.

(vi) The reaction of benzenediazonium chloride with silver, lead, mercury, antimony, bismuth, copper, iron, tin and nickel. None of these metals will react easily with either alkyl or acyl halides, but all are attacked by atomic or molecular chlorine, to which they will supply electrons. Many of them also are attacked by free alkyl radicals.

(vii) The formation of phenylmercuric chloride with metallic mercury and of triphenylstibine dichloride with metallic antimony. These again are reactions which require reagents of strong electron-seeking character, for the phenyl group in each case is bound to the metallic atom in the product by a covalent link. Alkyl or aryl halides do not react with either mercury or antimony alone; the free alkyl radicals, however, react instantaneously.

A very strong case can therefore be put forward to justify the theory of the non-ionic fission of nitrogen from aromatic diazo-compounds in the presence of non-hydroxylic solvents on the basic of the new experimental evidence detailed above. As additional evidence it may be mentioned that Möhlau and Berger (*Ber.*, 1893, **26**, 1994) found that benzenediazonium chloride gave diphenyl, phenylnaphthalene, and phenylpyridine (not phenylpyridinium chloride) on reaction with benzene, naphthalene, and pyridine respectively. It thus reacts with these substances just as do diazobenzene acetate and diazobenzene hydroxide (Grieve and Hey, J., 1934, 1797).

In a private communication, however, Professor R. Robinson has very kindly pointed out that the reactions discussed above could all be considered as typical interactions between covalent diazobenzene chloride and another reagent. Diazobenzene chloride, like any other *N*-chloroamine (*e.g.*, dichloramine-T), should contain a "positive" or "kationoid" halogen atom. It should therefore be capable of chlorinating acetone and of reacting with metals. The formation of the organo-metallic compounds is a little difficult to understand upon this theory, for it is not easy to conceive why an "anionoid" phenyl (or Ph·N:N) group should react with mercury or antimony in addition to the "kationoid" chlorine group. From inspection of the reaction as a whole, however, it is evident that these metals act by supplying two extra electrons to each molecule of the decomposing diazo-compound, and this may occur during, and not subsequent to, the disruption of the diazo-structure.

The Properties and Reactivity of "Positive" Halogen Compounds.—Since mercury is one of the inert metals, it was of interest to see whether other *N*-halogen compounds would react with it. Solutions of dichloramine-T in dry acetone, benzene, and carbon tetrachloride were refluxed with mercury; as soon as the solutions were warmed, reaction set in, giving a white insoluble mixture of mercurous chloride with the mercuric salt of toluene-*p*-sulphonamide. This reaction certainly provides conclusive evidence of the great electron-seeking character of *N*-chlorine compounds, showing that their halogen reactivity is comparable with that of free halogen atoms.

Only by making quantitative kinetic measurements of the rate of the decomposition processes can one decide between the alternative hypotheses of (*a*), a free radical decomposition, followed by an interaction of both the radicals produced as a covalent bond breaks with vicinal molecules, and (*b*), a bimolecular decomposition upon activated collision with another reactant, since, for any bimolecular decomposition process, (*b*), one can as yet give no more than a vague pictorial representation of the nature of the collision complex. At all events one cannot provide any ***experimental*** evidence to demonstrate how bonds are broken

in a bimolecular process, for the nature of the ultimate products gives no information as to whether or not there is a scission of electron duplets. Thus a bimolecular reaction, A:B + C:D ⟶ A:C + B:D may equally well be

(*b* i)
$$\begin{array}{c}\text{A:B}\\+\\\text{C:D}\end{array}\longrightarrow\left\{\begin{array}{cc}\text{A:}&\text{B}\\\text{C}&\text{:D}\end{array}\right\}\longrightarrow\begin{array}{c}\text{A}\\\because\\\text{C}\end{array}+\begin{array}{c}\text{B}\\\because\\\text{D}\end{array}$$

(polar in mechanism with no scission of electron duplets)

or

(*b* ii)
$$\begin{array}{c}\text{A:B}\\+\\\text{C:D}\end{array}\longrightarrow\left\{\begin{array}{cc}\text{A}\cdot&\cdot\text{B}\\\text{C}\cdot&\cdot\text{D}\end{array}\right\}\longrightarrow\begin{array}{c}\text{A}\\\because\\\text{C}\end{array}+\begin{array}{c}\text{B}\\\because\\\text{D}\end{array}$$

(non-ionic in mechanism with scission of electron duplets).

The initiation energetics of the two reaction processes will, however, be different, for the actual transition state will be that requiring the lesser energy increment. Now, *since chlorine is an electronegative element, much more energy will be needed to form a transient Cl^+ kation, containing but six electrons in its outer shell, than a transient neutral atom containing seven electrons, and hence, even in a bimolecular reaction of a compound containing an electron-seeking halogen atom, the process (*b* ii) may be more probable than the process (*b* i). If one examines critically the reactions of compounds containing electrophilic (*i.e.*, "kationoid") halogen atoms, one finds that no decisive evidence can be brought forward to refute an assertion that all these compounds may interact *so that the electron duplet which binds the halogen is broken momentarily with production* of a pair of neutral radicals each of which has a tendency to rectify this electron deficit by acquiring, or sharing, an extra electron from another reagent. In brief, all compounds containing electrophilic halogen atoms are oxidising agents which, like bromine or iodine molecules, tend to acquire two more electrons.

The possibility that reactions of compounds containing electrophilic halogen atoms are all reactions involving non-ionic bond fission opens up too wide a field of investigation to be discussed adequately in this paper, but attention may be directed to some significant work of Kharasch, Alsop, and Mayo (*J. Organic Chem.*, 1937, **2**, 76) and of Kharasch, Sternfeld, and Mayo (*J. Amer. Chem. Soc.*, 1937, **59**, 1655), who have shown that two compounds *which have long been regarded as typical substances containing electrophilic or "positive"* halogens, *viz.*, carbon tetraiodide and α-bromoacetoacetic ester, are stable except in the presence of oxygen or peroxides, which are substances now considered to catalyse the formation of free halogen atoms.

In conclusion, the author wishes to point out that the reactions of benzenediazonium chloride are not unique amongst those of diazo-compounds, but are paralleled exactly by those of substances such as diazobenzene acetate (Part I) and diazobenzene hydroxide (Part III; following paper), which do not contain any covalent nitrogen-to-halogen linkages. Moreover a large number of experimental facts, drawn from numerous branches of organic chemistry, indicate that free neutral radicals can exist momentarily in solutions and that they have exactly the properties which have been ascribed to the neutral phenyl radical and to atomic chlorine in this paper (compare Hey and Waters, *Chem. Reviews*, 1937, **21**, 169).

Experimental.

Benzenediazonium chloride was prepared by the method of Hantzsch and Jochem (*Ber.*, 1901, **34**, 3337) as improved by Pray (*loc. cit.*). For use, the hygroscopic white solid was washed with dry ether, then with the solvent to be employed, and rapidly transferred, whilst still damp with this solvent, to the reaction flask. No attempt was made either to dry or to preserve it. The flask was provided with a reflux condenser and a calcium chloride guard-tube in every reaction.

Reaction with Acetone.—(a) 10 G. of benzenediazonium chloride were covered with 50 c.c. of A.R. acetone. Hardly any reaction occurred at room temperature, but at 50° there was a regular evolution of both nitrogen and hydrogen chloride and the mixture became purplish-

brown. When reaction had slackened, the mixture was refluxed for 1 hour and the acetone was then distilled off on the water-bath. 20 C.c. of pure hexane were added to the distillate to extract any aromatic contents, and the acetone was dissolved with aqueous sodium bisulphite. The residual hexane solution, which was shown to contain an aromatic compound by the iodic acid reaction of Masson and Race (this vol., p. 1718), was nitrated. From the nitration product was separated a small quantity of a yellowish oil, which reacted with aniline in dilute alcohol to give 2 : 4-dinitrodiphenylamine, m. p. 157°. (Isolation of 2 : 4-dinitrodiphenylamine, as described above, was regularly used as a diagnostic test for the presence of small quantities of chlorobenzene: larger quantities could be characterised by the separation of solid nitration products.) The residue from distillation of the acetone was distilled in steam and gave a small quantity of a yellow oil, insoluble in alkali, which on fractionation yielded a little chlorobenzene together with traces of products of higher boiling point.

(b) *Reaction in neutral solution.* To obviate side reactions due to the presence of hydrogen chloride the decomposition was repeated, with 20 g. of benzenediazonium chloride, 20 g. of dry precipitated chalk, and 100 c.c. of acetone. Reaction set in at 45° and was easily regulated. After refluxing for 1 hour, the mixture was cooled and the solid residue after filtration was extracted with dry ether. The extract was fractionated in an all-glass apparatus. The fraction, b. p. 40—100°, was washed repeatedly with aqueous sodium bisulphite and refractionated; it then gave 2·2 g. of benzene, b. p. 80—82°, which was converted into *m*-dinitrobenzene, m. p. and mixed m. p. 90—91°. Above 100° chloroacetone distilled, b. p. 118—119° (yield, after refractionation, 6·1 g.), identified by hydrolysis, colour reaction with alkali, and by conversion into its 2 : 4-dinitrophenylhydrazone, m. p. 124° (compare Bülow and Siedel, *Annalen*, 1924, **439**, 48), and into its semicarbazone, m. p. 147—148° (decomp.) after crystallisation from benzene [Found (micro-analysis by Dr. G. Weiler): C, 32·5; H, 5·4; N, 27·8; Cl, 23·7. Calc.: C, 32·1; H, 5·4; N, 28·1; Cl, 23·7%]. This is in accord with Hoogeveen and Jansen (*Rec. trav. chim.*, 1932, **51**, 262), who describe the semicarbazone as decomposing at "about 150°," but not in accord with Michael (*J. pr. Chem.*, 1899, **60**, 286; compare Heilbron's "Dictionary"), who, however, allowed this easily hydrolysed substance to stand for several hours with water.

No chlorobenzene could be found under these conditions and no other definite product could be isolated from the tarry residue.

Reaction under Hexane.—8 G. of benzenediazonium chloride, after being washed with dry hexane, were covered with 60 c.c. of pure hexane. It remained unaltered for a day at room temperature, but at 50° the solid became sticky and both nitrogen and hydrogen chloride were evolved with such rapidity that the reaction had to be controlled by rapid cooling. The hexane was distilled off and found, by the iodic acid reaction, to contain chlorobenzene (identified as 2 : 4-dinitrodiphenylamine). The purplish residue was distilled in steam; from the distillate, ether extracted 3·0 g. of chlorobenzene, b. p. 130—134°, and about 1 g. of a substance, b. p. 180—220°, which could be nitrated (product, m. p. 179—186°) but not identified.

Reaction with Carbon Tetrachloride.—Benzenediazonium chloride (from 22 g. of aniline hydrochloride) was carefully washed with dry ether, then several times with carbon tetrachloride which had been dried with sodium, and quickly transferred to a flask containing 200 g. of dry carbon tetrachloride. No reaction occurred below 60°, the white powder floating in the clear liquid, but at this temperature decomposition set in and the solid softened with some frothing. Cooling in ice and water was necessary to control the reaction. A large quantity of hydrogen chloride was liberated and the mixture became dark purple as if an azine dye had been produced. When reaction had ceased, the carbon tetrachloride was distilled off on the water-bath, and the residue steam-distilled. The distillates gave 8 g. of chlorobenzene, b. p. 132°, which was identified by nitration. Phenol also was formed, but the quantity isolated (less than 1 g.) seemed scarcely an amount equivalent to the quantity of hydrogen chloride which had been liberated.

Reaction with Ethyl Iodide (compare Oddo, *Gazzetta*, 1890, **20**, 631).—6 G. of benzenediazonium chloride were mixed with 30 c.c. of ethyl iodide, and reaction induced by warming to 60°; nitrogen and a hydrogen halide were then evolved. After 1 hour's refluxing the excess of ethyl iodide was distilled off, and the residue distilled in steam. The distillate was washed with alkali and fractionated, giving (i) 1·5 g. of chlorobenzene, b. p. *ca.* 130°, identified by nitration to *p*-chloronitrobenzene, m. p. and mixed m. p. 83°, and (ii) 1·2 g. of iodobenzene, b. p. 184—187°, identified by conversion into *p*-iodonitrobenzene, m. p. and mixed m. p. 174°.

Reaction with Ethyl Acetate.—8 G. of benzenediazonium chloride were washed with dry ethyl acetate and then placed in 60 g. of this solvent. Reaction started at 50—60° and was completed by refluxing for 1 hour. Both nitrogen and hydrogen chloride were evolved. The

ethyl acetate was then distilled off on the water-bath, and the residue distilled in steam. By treatment with pure hexane, followed by hydrolysis with alkali in excess, the ethyl acetate fraction was shown to contain a little chlorobenzene (identified as 2 : 4-dinitrodiphenylamine) and from the steam-distillate were separated 1·0 g. of chlorobenzene, identified by nitration to 2 : 4-dinitrochlorobenzene, m. p. and mixed m. p. 53°, and 1·4 g. of phenol. There was no evidence of the formation of an ester of high boiling point.

To another mixture of equal bulk were added 10 g. of dry precipitated chalk, and the reaction was carried out as above. The ethyl acetate fraction gave a positive reaction with Schiff's reagent and again contained a little chlorobenzene. Benzene was not found. The steam-distillate yielded 3·0 g. of chlorobenzene, identified by conversion into *p*-chloronitrobenzene.

Reaction between Benzenediazonium Chloride and Mercury.—5 G. of benzenediazonium chloride, 10 g. of calcium carbonate, and 20 g. of mercury were mixed in 40 c.c. of acetone. Reaction set in *in the cold* with evolution of heat. The mixture was well shaken and cooled in water. After completion of the reaction by ½ hour's refluxing, the acetone was distilled off, and the residue treated with dilute acetic acid, which yielded a solution containing both calcium and chloride ions. The insoluble remainder was extracted (Soxhlet) with benzene, and from the benzene extract 3·1 g. of phenylmercuric chloride, m. p. 254°, were separated. The residue insoluble in benzene was a mixture of mercury and mercurous chloride which blackened instantly on treatment with ammonia.

Reaction between Benzenediazonium Chloride and Antimony.—(a) 5 G. of benzenediazonium chloride, 10 g. of calcium carbonate, and 20 g. of powdered antimony were mixed in 40 c.c. of acetone; reaction commenced instantly and had to be controlled by cooling the mixture in water. After ½ hour's refluxing on the water-bath, the acetone was evaporated. The residue on treatment with water evolved some carbon dioxide, probably on account of hydrolysis of antimony chloride, which would produce acid to interact with the calcium carbonate. The solution contained only calcium and chloride ions, but after the residue had been warmed with sodium hydrogen tartrate solution an extract containing a considerable quantity of an antimony salt was obtained. The remainder from this treatment was washed with warm dilute hydrochloric acid in excess and then treated with warm sodium hydroxide solution. The alkaline extract gave on acidification a gelatinous white precipitate, insoluble in hydrochloric acid but soluble in aqueous ammonia, which contained both carbon and antimony (positive Marsh test; carbon dioxide formed on heating with copper oxide), and was presumed to be a phenyl-stibonic or -stibinic acid. It gave an insoluble barium salt.

(b) Benzenediazonium chloride (from 22 g. of aniline hydrochloride) was shaken with a mixture of 30 g. of powdered antimony and 10 g. of calcium carbonate in 100 c.c. of acetone. At once a vigorous reaction set in, which continued when the mixture was cooled in ice and water. After completion of the reaction by 2 hours' refluxing, the product was cooled, the liquid filtered, and the solid washed with more acetone. By evaporation of the acetone solutions a solid was obtained from which, by crystallisation from alcohol containing some hydrochloric acid, 3·1 g. of triphenylstibine dichloride, m. p. and mixed m. p. 143° were separated (Found: Sb, 28·7. Calc.: Sb, 28·6%). The residues from this crystallisation seemed to contain phenylstibonic acids, probably formed by hydrolysis of arylstibonyl chlorides.

Reaction between Benzenediazonium Chloride and Other Metals.—5 G. portions of benzenediazonium chloride were added to separate mixtures of 10 g. of calcium carbonate, 40 c.c. of acetone, and 20 g. portions of powdered lead, bismuth, and tin. Portions of 2 g. of benzenediazonium chloride and 2 g. of calcium carbonate in 20 c.c. of acetone were treated with 10 g. portions each of iron and nickel filings, and also with 5 g. of copper bronze powder and with 3 g. of thin silver foil.

In each case reaction started in the cold and the mixture had to be cooled in water. After refluxing for ½ hour, the acetone was evaporated from each reaction mixture, and the residues were examined as follows.

From the reaction mixture with lead a little lead chloride was extracted by means of hot water, and a considerable quantity of a lead salt by extraction with cold dilute acetic acid.

From the mixture with bismuth a solution containing bismuth ions in quantity was obtained by extraction with warm 2N-hydrochloric acid. From that with tin a solution containing stannous ions in quantity was obtained by extraction with cold dilute acetic acid. This reagent had scarcely any action upon the tin powder alone.

Aqueous extraction of the reaction mixture with nickel gave a pale green solution containing nickel ions, and the formation of a green nickel salt was most evident. Similarly a green salt was produced from the reaction with iron, and an aqueous extract contained ferrous ions.

By ammoniacal extraction the reaction mixtures with copper and with silver were proved to contain cuprous and silver chloride respectively.

Reactions of Dichloramine-T with Mercury.—(a) 20 G. of mercury were shaken with a solution of 5 g. of dichloramine-T in 25 c.c. of acetone, and the mixture warmed. Reaction soon occurred and a bulky white precipitate formed.

Similar reactions were carried out, 20 g. portions of mercury being used with a solution of 5 g. of dichloramine-T in 60 g. of sodium-dried benzene and with a solution of 5 g. of dichloramine-T in 100 g. of dry carbon tetrachloride. In each case reaction rapidly occurred on warming, with the formation of an insoluble white precipitate. This precipitate was extracted with the solvent employed. The residue was then extracted with hot water and gave a solution containing mercuric ions. Dilute hydrochloric acid also removed a solid, which crystallised from the solution on cooling and proved to be *p*-toluenesulphonamide. In each case there remained a bulky white residue, which blackened instantly on treatment with aqueous ammonia and was therefore presumed to be mercurous chloride.

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425. *Decomposition Reactions of the Aromatic Diazo-compounds. Part III. Some Non-ionic Reactions of Diazobenzene Hydroxide.*

By WILLIAM A. WATERS.

Experimental evidence is brought forward to support the view that diazobenzene hydroxide, Ph·N:N·OH, which is formed by the hydrolysis of sodium benzenediazotate, undergoes decomposition with elimination of nitrogen and the production of the free neutral phenyl, Ph·, and hydroxyl, ·OH, radical.

For example, diazobenzene hydroxide decomposes in carbon disulphide to yield diphenyl disulphide, Ph·S·SPh, and in *cyclo*hexane to yield benzene, together with more complex products. In the absence of any other organic substance an aqueous solution of sodium benzenediazotate decomposes with the formation of a trace of benzene.

According to the hypothesis of non-ionic fission of diazobenzene hydroxide there should be produced two electrophilic groups, Ph· and ·OH, and in consequence one should observe an oxidising action similar in character to that of iodine. Oxidising reactions of alkaline diazo-solutions have already been commented on by Angeli, and it is now possible to explain the occurrence of these reactions without recourse to his special structure for the normal diazotates. The Bart synthesis of phenylarsonic acids is also thought to include a non-ionic reaction.

WHILST studying the preparation of diphenyl derivatives by Gomberg's method, Grieve and Hey (J., 1934, 1797) came to the conclusion that the active reagent was the diazoaryl hydroxide, Ar·N:N·OH, which decomposed to give free neutral aryl radicals. These then reacted with an aromatic compound, C_6H_5R, to yield a *p*-substituted diphenyl derivative, *p*-Ar·C_6H_4R, irrespective of the polar character of R. A similar non-ionic fission was considered to take place in diazobenzene acetate (nitrosoacetanilide), since it was another phenylating agent of the same non-polar character.

In Part I (this vol., p. 113) it was shown that diazobenzene acetate reacted with a number of organic liquids such as carbon tetrachloride, carbon disulphide, hexane, and *cyclo*hexane to yield products which could have been produced only if a highly active phenyl radical had been present during the reaction. It was therefore of interest to examine the reaction between diazobenzene hydroxide and the stable non-aromatic liquids carbon disulphide and *cyclo*hexane, the procedure of Hey being adopted.

Aniline in dilute sulphuric acid was diazotised, and the organic solvent added to the filtered diazonium salt solution. The cold mixture was made alkaline and allowed to decompose slowly. From the reaction with carbon disulphide, diphenyl disulphide was

isolated, and from the reaction with *cyclo*hexane conclusive evidence was obtained of the production of benzene. Further Hey (private communication) has found that, if carbon tetrachloride is used, chlorobenzene is obtained. Thus a complete analogy can be traced between the reactions of diazobenzene hydroxide and of diazobenzene acetate. The general course of the reactions described in the experimental section of this paper leaves little doubt that the reactions occur in the organic liquid and not in the aqueous phase, and, in earlier discussions of the mechanism of the diphenyl synthesis, it has already been suggested that organic solvents extract diazobenzene hydroxide from alkaline solutions of the readily hydrolysed sodium benzenediazotate (Gomberg and Pernert, *J. Amer. Chem. Soc.*, 1926, **48**, 1373).

Non-ionic reactions involving free neutral radicals such as Ph· and ·OH are inevitably complex, since the neutral radicals are extremely reactive entities which interact with practically the first molecule they encounter. Consequently a large amount of a complex tar is produced during the decomposition of alkaline diazo-solutions. This, as Hey and others have already shown, contains complex polyphenyls, which result from reactions between aryl radicals and some of the molecules of simpler reaction products formed at early stages of the decomposition of the diazo-compound.

Since the reaction between diazobenzene hydroxide and *cyclo*hexane substantiated the occurrence of the reaction $\mathrm{Ph\cdot + HR \longrightarrow PhH}$, it was of interest to determine whether benzene might also result from the complex intermolecular decomposition of diazobenzene hydroxide in absence of other molecules except water molecules. Consequently a benzene-diazonium sulphate solution was made alkaline and allowed to decompose gradually. It gave a considerable quantity of a tar insoluble in alkali, which, by extraction with hexane, was shown to contain a trace of benzene. Hence the intermolecular decomposition of diazobenzene hydroxide possibly does include the hydrogenation of some of the free radicals by other of the aromatic molecules, though as an alternative it may be suggested that free phenyl radicals can abstract hydrogen from water molecules, a process which is the reverse of the usual breakdown of aqueous solutions of diazonium compounds to give phenols.

These experiments, therefore, supporting those of Grieve and Hey, show that it is quite justifiable to interpret a number of reactions of aromatic diazo-compounds occurring in neutral or alkaline conditions as reactions involving neutral radicals. Some other reactions which may be of this type receive mention below.

In the preceding paper (Part II) it has been pointed out that substances which dissociate to give a pair of neutral radicals are oxidising agents. Hence one should find that diazobenzene hydroxide solutions are, like iodine solutions, oxidising agents. Angeli (*Ber.*, 1930, **63**, 1977) brought forward a good deal of experimental evidence to show that diazotates were strong oxidisers in order to justify his structural formula, $\begin{array}{c}\mathrm{Ph{\cdot}N{:}NH}\\ \downarrow\\ \mathrm{O}\end{array}$ for *normal* diazobenzene hydroxide, to which Hantzsch had assigned the *syn*-diazo-structure $\begin{array}{c}\mathrm{Ph{\cdot}N}\\ \|\\ \mathrm{HO{\cdot}N}\end{array}$.

The experimental fact that diazo-compounds are oxidising agents is not generally appreciated, since when one makes a diazonium salt solution by the use of a nitrite the resulting mixture generally contains a little free nitrous acid. If, however, one adds pure benzenediazonium sulphate solution to a cold aqueous solution of leucomethylene-blue, nitrogen is evolved and the blue colour is at once restored. Sodium benzenediazotate will oxidise quinol (Orton and Everatt, J., 1908, **93**, 1010), sodium arsenite, ammonium sulphide, potassium ferrocyanide, and other substances under conditions in which nitrogen is evolved and either benzene or diphenyl is formed. Reagents which reduce diazonium salts to phenylhydrazine undoubtedly act in another manner. Hantzsch and Strasser (*Ber.*, 1931, **64**, 655) have shown that there are serious objections to the structural formula of Angeli, which represents a substance which should hydrolyse at once to a mixture of nitrobenzene and ammonia, but nevertheless they have not been able to explain the oxidising power of the diazotates by means of the older formulæ. The hypothesis of non-ionic fission of diazobenzene hydroxide will, however, suffice to explain this property of the diazotates.

Another reaction of diazobenzene hydroxide which illustrates its similarity in oxidising properties to iodine is the Bart synthesis of arylarsonic acids, in which an arsenite is

$$Ar{\cdot}N{:}N{\cdot}OH + Na_2HAsO_3 \longrightarrow N_2 + Ar{\cdot}AsO(ONa)_2 + H_2O$$

converted into a derivative of quinquevalent arsenic. This reaction occurs spontaneously in a cold neutral solution, without recourse to any copper derivative as catalyst, and it has been noticed (Schmidt, *Annalen*, 1920, **421**, 159; Bart, *ibid.*, 1922, **429**, 55) that diphenyl derivatives are regular by-products, as would be expected if free aryl radicals were present during the course of the reaction. The formation of covalent organo-metallic compounds (preceding paper) is also of obvious significance in connection with the mechanism of the Bart reaction.

The production of diaryl disulphides in interactions between diazo-solutions and neutral or alkaline solutions of sulphides or thiosulphates may again be due to the transient presence of neutral radicals. Further extensions of this hypothesis suggest themselves and perhaps a reinvestigation of the Sandmeyer reaction may reveal that cuprous salts operate as catalysts by favouring the non-ionic decomposition process.

Experimental.

The Reaction of Diazobenzene Hydroxide.—*With carbon disulphide.* 20 G. of aniline sulphate in 200 c.c. of N-sulphuric acid were diazotised with sodium nitrite (7 g.) and 100 c.c. of carbon disulphide were added to the filtered diazo-solution at 0°. The carbon disulphide layer remained colourless. 100 C.c. of 2N-sodium hydroxide were then added slowly with shaking. The mixture had an alkaline reaction, the carbon disulphide layer became dark brown, and the aqueous layer was practically colourless. When the mixture was allowed to warm, nitrogen was evolved from the carbon disulphide layer. The reaction was completed by heating for 1 hour on the water-bath and the carbon disulphide was then distilled off. The aqueous residue was decanted from an insoluble tarry red mass, which on treatment with acetic acid yielded a solid product. This, by repeated crystallisation from acetic acid and from methyl alcohol, gave colourless crystalline diphenyl disulphide (3·8 g.), m. p. and mixed m. p. 61·5°.

With cyclo*hexane.* 20 G. of aniline sulphate, diazotised in 200 c.c. of N-sulphuric acid as before, were mixed with 100 c.c. of benzene-free *cyclo*hexane and made alkaline at 0° with 100 c.c. of 2N-sodium hydroxide. Tar was formed in the dark *cyclo*hexane layer and nitrogen was at once evolved. The reaction was completed by 1 hour's heating on the water-bath. After cooling, the *cyclo*hexane layer was separated, washed successively with acid and alkali, and distilled from a water-bath. 1 C.c., tested by the iodic acid method of Masson and Race (this vol., p. 1718), gave a positive reaction for benzene. The remainder of the distillate was therefore nitrated, 30 c.c. each of fuming nitric and concentrated sulphuric acid being used, and, after pouring into water, the nitrated product was extracted with ether. The extract, after being washed with alkali, was concentrated and then gave *m*-dinitrobenzene (1·8 g.), m. p. (after recrystallisation from alcohol) and mixed m. p. 91°.

The reaction without added solvent. Another diazo-solution, prepared as before from 20 g. of aniline sulphate, was made alkaline at 0° with 100 c.c. of 2N-sodium hydroxide, under an efficient reflux condenser, and allowed to decompose slowly, the reaction finally being completed by 1 hour's heating on the water-bath. After slight cooling, 25 c.c. of hexane (B.D.H. "pure for spectroscopy") were added, as a vehicle for the collection of any benzene, and the mixture was distilled from a water-bath. There remained a considerable quantity of a hardish tar, insoluble in alkali and smelling noticeably of phenyl *iso*cyanide. Phenol, therefore, is not a major product of the decomposition. The hexane distillate, after being washed with acid and with alkali, gave a positive test for benzene by the iodic acid method, and on nitration a few mg. of *m*-dinitrobenzene, m. p. 90—91° (after crystallisation from dilute methyl alcohol), were obtained in needles.

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FORMULA INDEX.

THE following index of organic compounds of known empirical formula is arranged according to Richter's system (see *Lexikon der Kohlenstoff-Verbindungen*).

The elements are given in the order C, H, O, N, Cl, Br, I, F, S, P, and the remainder alphabetically.

The compounds are arranged—

Firstly, in groups according to the number of carbon atoms (thus C_1 group, C_2 group, etc.).

Secondly, according to the number of other elements besides carbon contained in the molecule (thus 5 IV indicates that the molecule contains five carbon atoms and four other elements).

Thirdly, according to the nature of the elements present in the molecule (given in the above order).

Fourthly, according to the number of atoms of each single element (except carbon) present in the molecule.

Salts are placed with the compounds from which they are derived. The chlorides, bromides, iodides, and cyanides of quaternary ammonium bases, however, are registered as group-substances.

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$C_3H_2OBr_4$ *as*-Tetrabromoacetone, 1944.
$C_3H_2N_4S_3$ Dithiocarbimidothiourea, 1361.
$C_3H_5O_2Br$ α-Bromopropionic acid, alcoholysis and hydrolysis of, 1208; and its sodium salt, action of silver salts on, 1243.
$C_3H_8O_2N_6$ Mesoxalhydrazide hydrazone, 1812.

3 IV

$C_3H_6NCl_3S$ *S*-Dimethylaminotrichloromethylthiol, 1631.
$C_3H_8O_2N_6S$ *s*-Dicarbamidothiourea, 1360.
$C_3H_8Cl_4SHg_2$ Methyl ethyl sulphide dimercurichloride, 871.
$C_3H_9ClAsAu$ Chlorotrimethylarsinegold, 1832.
C_3H_9IAsAu Iodotrimethylarsinegold, 1832.

C_4 Group.

$C_4H_4N_4$ Aminoiminosuccinonitrile, hydrochloride of, 1436.
Diaminomaleinitrile, 920.
$C_4H_6O_4$ Acetyl peroxide, decomposition of, 1132.
C_4H_9Cl *tert.*-Butyl chloride, reaction of, with formic acid, 1852.
C_4H_9Br *tert.*-Butyl bromide, hydrolysis of, in acetone, 1853.
$C_4H_{11}N$ Diethylamine, salts of, with propionic acid, 1022.

4 III

$C_4H_3ON_5$ Cyano-1:2:3-triazolecarboxyamide, 1437.
$C_4H_4Cl_2S$ Dichlorodivinyl sulphide, 769.
$C_4H_7O_2Br$ Methyl α-bromopropionate, alcoholysis and hydrolysis of, 1208; action of silver salts on, 1243.
$C_4H_7O_5N$ Methyl α-nitratopropionate, 1249.
$C_4H_7N_3S$ 2-Amino-5-methyl-1:3:4-thiadiazine, and its salts, 558.
2-Keto-4-methyl-2:3-dihydrothiazole-2-hydrazone, and its picrate, 558.
$C_4H_8O_4N_2$ Tartramides, 1518.
$C_4H_8N_2S_2$ Ethylenebisthioformamide, 363.
$C_4H_9O_5N_3$ Acetyl-5-nitro-1-methoxyphthalaz-4-one, 1845.
$C_4H_{10}O_2Mn$ Manganese ethoxide, 1408.

4 IV

C_4H_4ONBr α-Bromocyanoacetone, 925.
$C_4H_{10}ClSAu$ Chlorodiethylsulphidegold, 1833.
$C_4H_{10}Cl_4SHg_2$ Methyl *n*-propyl sulphide mercurichloride, 871.
$C_4H_{12}N_2Cl_2Pd$ *iso*Butylenediaminopalladous chloride, 948.
$C_4H_{12}N_2Cl_2Pt$ β-Methyltrimethylenediaminoplatinous chloride, 1550.
$C_4H_{17}N_4Cl_4Co$ *trans*-Trichloroethylenediaminocobaltiethylenediamine hydrochloride, 509.
$C_4H_{18}O_2N_4Cu$ Bisethylenediaminocupric hydroxide, salts of, 948.

4 V

$C_4H_9NSAsAu$ Thiocyanatotrimethylarsinegold, 1832.
$C_4H_{19}O_2N_4Cl_4Co_2$ *trans*-Hydroxoaquobisethylenediaminecobaltic cobaltochloride, 509.

C_5 Group.

C_5H_6 *cyclo*Pentadiene, determination of, 797.

5 II

C_5H_5N Pyridine, compounds of, with cobaltous salts, 1558.
$C_5H_{10}O_2$ *tert.*-Butyl formate, 1852.
$C_5H_{11}N$ Piperidine, physical properties of mixtures of, with propionic acid in benzene, 462.
$C_5H_{12}O_4$ Pentaerythritol, crystal structure of, 883.

5 III

$C_5H_4N_6S_5$ 3:5-Dithiocarbimidothiocarbonyldithiourea, 1362.
$C_5H_6N_4S_3$ *NN′-Dithiocarbimidodimethylthiourea, 1361.*
C_5H_9ON α-Piperidone, association of, 495.
$C_5H_{10}O_2S$ α-Ethylsulphonyl-Δ^{β}-propylene, 312.
$C_5H_{10}O_3N_2$ αδ-Diamino-γ-ketovaleric acid, dihydrobromide of, 1167.
$C_5H_{10}O_4N_2$ *dl*-Erythro-α-hydroxy-β-methoxysuccindiamide, 1518.
$C_5H_{12}OS$ γ-Hydroxy-α-ethylthiopropane, 314.
$C_5H_{12}O_2N_2$ Ethyl 5-hydroxyvalerate hydrazide, 374.

5 IV

$C_5H_4O_2N_6S_3$ 3:5-Dithiocarbimidothiocarbonyldiurea, 1360.
$C_5H_{10}O_2Br_2S$ βγ-Dibromo-α-ethylsulphonylpropane, 312.

$C_5H_{10}NCl_3S$ *S*-Diethylaminotrichloromethylthiol, 1631.
$C_5H_{11}OClS$ γ-Chloro-β-hydroxy-α-ethylthiopropane, 313.
$C_5H_{11}O_3ClS$ γ-Chloro-β-hydroxy-α-ethylsulphonylpropane, 313.

C_6 Group.

C_6H_6 Benzene, structure of, 1728.
C_6H_{10} β-Methyl-$\Delta^{\alpha\delta}$-pentadiene, 1073.
C_6H_{12} Tetramethylethylene, polymerisation of, 1039.
C_6D_6 Hexadeuterobenzene, Raman spectrum of, 1728.

6 II

C_6H_5Cl Chlorobenzene, polarisation of, in ethers, 1051.
C_6H_5Br Bromobenzene, moments and polarisation of, in various solvents, 135.
C_6H_8N Substance, from β-dimethylaminopropiophenone and hydrazine, 1931.
$C_6H_6N_4$ 4-Amino-5-cyano-2-methylpyrimidine, 366.
C_6H_7N Aniline, reaction of, with iodine, 1365; nitrite of, decomposition of, 1129.
$C_6H_8O_4$ β-Methyl-Δ^{β}-propylene-αγ-dicarboxylic acids, 726.
Norhomopilopic acid, 1062.
$C_6H_{10}O_2$ *cyclo*Hexanone peroxide, 373.
$C_6H_{10}O_3$ Tetrahydrofurylacetic acid, 721.
$C_6H_{10}O_4$ *d*-Ethylsuccinic acid, 230.
$C_6H_{11}N$ *bicyclo*[1:2:2]Aza-1-heptane, and its salts, 1526.
$C_6H_{12}O$ β-Methyl-Δ^{β}-penten-δ-ol, 1076.
$C_6H_{12}O_6$ Dihydroxyacetone dimeride, catalysis of depolymerisation of, 1947.
Glucose, heats of activation in mutarotation of, 1413.

6 III

$C_6H_2O_3S$ Thiophen-2:3-dicarboxylic anhydride, 916.
$C_6H_2N_2S$ 2:3-Dicyanothiophen, 917.
$C_6H_3ON_3$ 3:4-Dicyano-5-methyl*iso*oxazole, 927.
$C_6H_4ON_4$ 6-Hydroxy-2:3-dicyanodihydropyrazine, 1435.
$C_6H_4N_3Cl$ 4-Chloro-5-cyano-2-methylpyrimidine, 366.
$C_6H_5ON_3$ 4-Hydroxy-5-cyano-2-methylpyrimidine, 366.
$C_6H_5O_2N$ *p-Benzoquinoneoxime, tautomerism of, with p-nitrosophenol, 520.*
Nitrobenzene, polarisation of, in ethers, 1051.
$C_6H_5O_2N_3$ Cyano-5-methyl*iso*oxazolecarboxyamide, 927.
$C_6H_5N_2Cl$ Benzenediazonium chloride, reactions of, 2007.
$C_6H_6ON_2$ Diazobenzene hydroxide, reactions of, 2014.
$C_6H_6ON_4$ Acetamidoiminosuccinonitrile, 1436.
$C_6H_9N_3S$ 2-Keto-2:3-dihydrothiazole-2-*iso*propylidenehydrazone, 559.
$C_6H_7O_3N_3$ 5-Methyl*iso*oxazole-3:4-dicarboxyamide, 927.
$C_6H_8ON_4$ 4-Amino-2-methylpyrimidine-5-carboxyamide, 366.
C_6H_9ON Tetrahydrofurylacetonitrile, 720.
$C_6H_{11}OBr$ *δ-Ethoxybutyl bromide, 816.*
$C_6H_{12}O_4N_2$ *dl*-Dimethoxysuccindiamide, 1518.
Tartarobismethylamides, 1518.
$C_6H_{13}ON$ 4-Piperidylcarbinol, and its picrate, 1526.
$C_6H_{14}O_2Mn$ Manganese *iso*propoxide, 1408.
$C_6H_{15}O_3Re$ Rhenium triethoxide, 1408.

6 IV

$C_6H_3O_2NS$ Thiophen-2:3-dicarboxylic imide, 916.
$C_6H_5N_2Cl_2I$ 2:4-Dichloro-5-iodomethyl-6-methylpyrimidine, 1508.
$C_6H_9O_2NS$ Ethyl α-thiocyanopropionate, 157.
$C_6H_9O_2NSe$ Ethyl α-selenocyanopropionate, 157.
$C_6H_9O_2N_3S$ *dl-Thiolhistidine, 1167.*
$C_6H_{15}ClPAu$ Chlorotriethylphosphinegold, 1832.
$C_6H_{15}ClAsAu$ Chlorotriethylarsinegold, 1833.
$C_6H_{15}IPAu$ Iodotriethylphosphinegold, 1832.
$C_6H_{15}IAsAu$ Iodotriethylarsinegold, 1833.

C_7 Group.

$C_7H_3N_3$ 2:3-*Dicyanopyridine, 919.*
$C_7H_8O_4$ 2-Keto-3-methyl-2:5-dihydrofuran-5-acetic acid, 1346.
α-Methylmuconic acid, 1347.
$C_7H_8N_2$ 3-Cyano-2:5-dimethylpyrrole, 925.
5-Cyano-2:3-dimethylpyrrole, 927.
$C_7H_{10}O_4$ Dihydro-α-methylmuconic acid, 1347.
$C_7H_{10}O_6$ 2-Methyl ascorbic acid, 832.
$C_7H_{10}O_7$ Gluco-ascorbic acid, 549.
$C_7H_{10}N_2$ 2:4:6-Trimethylpyrimidine, 494.

$C_7H_{12}O_2$ β-Ethoxyethylideneacetone, 1062.
$C_7H_{12}O_3$ Dimethyl xylal, 781.
αγ-Methylenedioxy-β-acetyl-β-methylpropane, 844.
β-Tetrahydrofurylpropionic acid, 719.
$C_7H_{12}O_6$ Methyl *dl*-erythrohydroxymethoxysuccinate, 1518.
2-Methyl γ-gluconolactone, 796.
$C_7H_{13}N$ Quinuclidine, synthesis of, 1990.
$C_7H_{13}Br$ Δ^6-*n*-Heptenyl bromide, 1973.
$C_7H_{14}O$ Δ^6-*n*-Heptenol, 1973.
$C_7H_{14}O_3$ Ethyl 5-hydroxyvalerate, 373.
$C_7H_{14}O_5$ 2:5-Dimethylxylofuranose, 1602.
$C_7H_{14}O_6$ α-Methylgalactopyranoside, 1924.
α-Methylglucopyranoside, 1924.

7 III

$C_7H_3O_2I_3$ 2:4:6-Tri-iodo-3-hydroxybenzaldehyde, 77.
$C_7H_3O_4N_3$ 2:4-Dinitrobenzonitrile, preparation of, 1746.
$C_7H_4O_2I_2$ 2:6-Di-iodo-3-hydroxybenzaldehyde, 77.
$C_7H_4O_6N_2$ 2:4-Dinitrobenzoic acid, preparation of, 1746.
$C_7H_5ON_3$ Cyanopyridinecarboxyamide, 919.
$C_7H_5O_2I$ 6-Iodo-3-hydroxybenzaldehyde, 77.
$C_7H_8O_2Na$ Sodium guaiacoxide, action of, with alkyl iodides, 1792.
$C_7H_8O_4S$ 2-Hydroxyphenylmethanesulphonic acid, sodium salt, 1350.
$C_7H_9ON_3$ 4-Phenylsemicarbazide, co-ordination compounds of, with metallic salts, 1357.
$C_7H_{10}O_{14}N_4$ β-Methylglucoside 2:3:4:6-tetranitrate, 1717.
$C_7H_{10}N_4S$ 4-Amino-5-thioformamidomethyl-2-methylpyrimidine, 367.
$C_7H_{11}ON$ 2-Ketoquinuclidine, 1990.
$C_7H_{11}O_6N$ Imino-*l*-gluco-ascorbic acid, 552.
$C_7H_{11}N_3S$ 2-Keto-4-methyl-2:3-dihydrothiazole-2-*iso*propylidenehydrazone, 557.
$C_7H_{12}ON_2$ 5-Acetyl-4:4-dimethylpyrazoline, 1556.
$C_7H_{12}O_{10}N_2$ β-Methylglucoside dinitrates, 1716.
$C_7H_{13}OBr$ γ-Tetrahydrofurylpropyl bromide, 720.
$C_7H_{14}O_4S_2$ αγ-Bis(ethylsulphonyl)propylene, 318.
$C_7H_{14}NI$ *bicyclo*[1:2:2]Aza-1-heptane methiodide, 1526.
$C_7H_{15}ON_3$ *dl*-Methyl*iso*propylacetaldehyde semicarbazone, 1045.
$C_7H_{15}O_6N$ 2-Methyl gluconamide, 796.
$C_7H_{16}O_2N_2$ Ethyl 7-hydroxyheptoate hydrazide, 373.
$C_7H_{16}O_5S_2$ β-Hydroxy-αγ-bis(ethylsulphonyl)propane, 318.

7 IV

$C_7H_3O_6N_2I$ Iododinitro-3-hydroxybenzaldehydes, 78.
$C_7H_4O_4NI$ 2-Iodo-6-nitrobenzoic acid, 1101.
$C_7H_4O_4N_6S_3$ *NN'*-Dithiocarbimido-*NN'*-dioxamylthiourea, 1361.
C_7H_6ONBr ω-Bromoacetylpyridine, 967.
$C_7H_{15}O_4ClS_2$ β-Chloro-αγ-bis(ethylsulphonyl)propane, 318.

C_8 Group.

$C_8H_6N_4$ 2:3-Dicyano-5:6-dimethylpyrazine, 921, 1436.
$C_8H_7N_3$ 3:4-Dicyano-2:5-dimethylpyrrole, 926.
C_8H_8O Acetophenone, action of phosphorus pentahalides on, 304.
$C_8H_8O_3$ Mandelic acid, acid salts of, 608.
4-Methoxy-2:5-toluquinone, preparation of, 1471.
$C_8H_8O_6$ 2-Keto-3-methyl-2:5-dihydrofuran-5-malonic acid, and its barium salt, 1346.
C_8H_9Cl α-Phenylethyl chloride, action of silver salts on, 1236.
$C_8H_{10}O_4$ Methyl 2-keto-3-methyl-2:5-dihydrofuran-5-acetate, 1346.
$C_8H_{10}O_6$ 2-Keto-3-methyltetrahydrofuran-5-acetic-5-carboxylic acid, 1347.
$C_8H_{10}N_4$ *iso*Butylideneaminoiminosuccinonitrile, 1436.
2:7-Dimethyldihydro-1:3:6:8-benztetrazine, and its hydrobromide, 1507.
$C_8H_{11}N$ 2:4:6-Trimethylpyridine, nitrate of, 302.
$C_8H_{12}O$ 2-Methyl-6-methylene*cyclo*hexanone, 57.
$C_8H_{12}O_4$ Homopilopic acids, 1060.
Norcaryophyllenic acids, resolution of, 1340.
Δ^4-*n*-Pentenylmalonic acid, 1973.
$C_8H_{12}O_6$ *iso*Dimethyl ascorbic acid, 831.
$C_8H_{12}O_7$ 2-Methyl gluco-ascorbic acid, 555.
3-Methyl *d*-gluco-ascorbic acid, 552.
$C_8H_{14}O_4$ γ-Carbethoxyvaleryl chloride, 72.
d- and *l*-Diethylsuccinic acids, 233.
$C_8H_{14}O_6$ Diethyl tartrate, green colour of, 963.
3:4-Dimethyl mannonolactone, 791.
$C_8H_{16}O_3$ Ethyl 6-hydroxyhexoate, 373.
$C_8H_{16}O_5$ 2:5-Dimethyl methylxylofuranosides, 1602.
2:3-Dimethyl γ-methylxyloside, 1603.

$C_8H_{16}O_6$ 4:6-Dimethyl *a*-glucose, 1716.
3:4-Dimethyl mannose, 791.
3:4:5-Trimethyl *d*-arabonic acid, 554.
$C_8H_{17}Cl$ 2-Chloro-6-methylheptane, 1589.
$C_8H_{17}Br$ *β*-*n*-Octyl bromide, action of silver salts on, 1236; *hydrolysis of*, 1192.
$C_8H_{17}I$ 2-Iodo-6-methylheptane, 1590.
$C_8H_{18}N_2$ Tetramethylpiperazines, 368.

8 III

$C_8H_4O_4Cl_2$ 3:6-Dichlorophthalic acid, hydrazine salt, 32.
$C_8H_5O_2I_3$ 2:4:6-Tri-iodo-3-methoxybenzaldehyde, 77.
$C_8H_5O_3N$ 3-Hydroxyphthalimide, 33.
$C_8H_5O_4N_3$ 3-Nitro-*N*-aminophthalimide, 1846.
$C_8H_5O_4Br$ 2-Bromo*iso*phthalic acid, 1305.
$C_8H_6O_2N_2$ *N*-Aminophthalimide, 20.
$C_8H_6O_2I_2$ 2:6-Di-iodo-3-methoxybenzaldehyde, 77.
$C_8H_6O_3N_2$ *5-Hydroxyphthalaz-1:4-dione*, and its sodium salt, 33.
$C_8H_6Cl_2S$ Phenyl *αβ*-dichlorovinyl sulphide, 769.
$C_8H_6Cl_4S$ Phenyl *ααββ*-tetrachloroethyl sulphide, 769.
$C_8H_7O_2N_3$ *N*-3-Diaminophthalimide, 30.
3:6-Diaminophthalimide, 589.
3:6-Dimethylpyridazine-4:5-dicarboxyimide, 928.
3-Hydrazinophthalimide, 591.
$C_8H_7O_3N$ 4-Cyano-2:5-dimethylfuran-3-carboxylic acid, 928.
Methyl 5-cyano-3-methylfuran-4-carboxylate, 928.
$C_8H_7O_5N_3$ 3-Nitro-2-carboxybenzhydrazide, 29.
$C_8H_8ON_2$ 4-Formyl-3-cyano-2:5-dimethylpyrrole, 926.
$C_8H_8O_2N_2$ 3-Cyano-2:5-dimethylpyrrole-4-carboxylic acid, 925.
5-Cyano-2:3-dimethylpyrrole-4-carboxylic acid, 927.
$C_8H_8O_2N_4$ Acetamidoacetimidosuccinonitrile, 1436.
N-Amino-3-hydrazinophthalimide, 591.
Diaminophthalaz-1:4-diones, 590.
5-Hydrazinophthalaz-1:4-dione and its sodium salt, 591.
3:6-N-Triaminophthalimide, 589.
$C_8H_8O_3S$ 5-Methylbenzylsultone, 1351.
$C_8H_8N_2S$ *N*-Thiocarbimidophenylmethylamine, 1362.
$C_8H_9O_2N_3$ *o*-Carbamylbenzhydrazide, 21.
C_8H_9NS Benzylthioformamide, 363.
$C_8H_{10}O_2N_4$ 3:6-Dimethylpyridazine-4:5-dicarboxyamide, 928.
$C_8H_{10}O_3N_2$ Ethyl 4-hydroxy-2-methylpyrimidine-5-carboxylate, 366.
$C_8H_{10}N_3Br$ 1-*p*-Bromophenyl-3:3-dimethyltriazen, 324.
$C_8H_{11}ON_3$ 4-*m*-Tolylsemicarbazide, co-ordination compounds of, with metallic salts, 1357.
$C_8H_{11}O_2N_3$ Ethyl 4-amino-2-methylpyrimidine-5-carboxylate, 366.
$C_8H_{11}O_4N$ Ethyl 2-pyrrolidone-3-oxalate, 1525.
$C_6H_{11}N_5S_2$ *2-Amino-1:4-dithiocarbamidobenzene*, 1360.
$C_8H_{12}N_4S$ 4-Amino-5-thioacetamidomethyl-2-methylpyrimidine, 1507.
$C_8H_{14}ON_2$ 5-Acetyl-3:4:4-trimethylpyrazoline, 1556.
$C_8H_{15}ON$ 2-Hydroxyoctahydropyrrocolines, and their salts, 1523.
$C_8H_{15}O_2N$ Ethyl piperidine-4-carboxylate, and its picrate, 1525.
$C_8H_{15}O_2N_3$ *β*-Ethoxyethylideneacetone semicarbazone, 1062.
$C_8H_{15}O_2Cl$ Ethyl 6-chlorohexoate, 721.
$C_8H_{15}O_2Br$ Ethyl 6-bromohexoate, 721.
$C_8H_{15}O_3N_3$ *αγ*-Methylenedioxy-*β*-acetyl-*β*-methylpropane semicarbazone, 844.
$C_8H_{16}O_2N_2$ *αγ*-Diacetyl-*β*-methylpropane dioxime, 302.
$C_8H_{16}O_2N_4$ Dinitroso-*ε*-2:3:5:6-tetramethylpiperazine, 369.
$C_8H_{16}O_4N_2$ *dl*-Dimethoxysuccinobismethylamide, 1518.
$C_8H_{17}O_6N$ 3:4-Dimethyl mannonamide, 791.
$C_8H_{20}Br_2Au_2$ Diethylbromogold, constitution of, 1690.

8 IV

$C_8H_2O_2N_2Cl_4$ Tetrachloro-*N*-aminophthalimide, 32.
$C_8H_3O_2NCl_2$ *4:5-Dichlorophthalimide*, 590.
$C_8H_4O_2N_2Cl_2$ 3:6-Dichloro-*N*-aminophthalimide, 31.
Dichlorophthalaz-1:4-diones, 32.
$C_8H_5O_2N_2Cl$ 3-Chloro-*N*-aminophthalimide, 31.
5-Chlorophthalaz-1:4-dione, 31.
$C_8H_5O_4NI_2$ 2:4-Di-iodo-6-nitro-3-methoxybenzaldehyde, 78.
$C_8H_6O_4NI$ Methyl 2-iodo-6-nitrobenzoate, 1101.
$C_8H_7O_5N_3S$ Phthalimide-3-hydrazine-*β*-sulphonic acid, sodium salt, 591.
$C_8H_8O_2N_2S$ *o*-Nitrobenzylthioformamide, 363.
$C_8H_8O_2N_4Cl_2$ 3:6-Dichlorophthalodihydrazide, 32.
$C_8H_6O_2BrI$ Methyl 5-bromo-2-iodobenzoate, 1101.
$C_8H_8O_5N_4S$ *N-Aminophthalimide-3-hydrazine-β-sulphonic acid*, sodium salt, 59
$C_8H_8NCl_3S$ Methylanilinotrichloromethylthiol, 1631.

$C_8H_{14}ONI$ 2-Ketoquinuclidine methiodide, 1990.
$C_8H_{24}N_4Cl_2Pt$ *iso*Butylenediamino-β-methyltrimethylenediaminoplatinous chloride, 1550.
$C_8H_{26}O_2N_4Cu$ Bis*iso*butylenediaminocupric hydroxide, salts of, 948.
$C_8H_{26}O_2N_4Pt$ Bis*iso*butylenediaminoplatinous hydroxide, salts of, 1550.
*iso*Butylenediamino-β-methyltrimethylenediaminoplatinous hydroxide, salts of, 1550.

8 V

$C_8H_9ON_4BrS$ 2-Thion-1-*p*-bromophenyldiurea, 1361.
$C_8H_{24}ON_8Cl_8Co_2$ *trans*-Dichlorobisethylenediaminecobaltic cobaltochloride, 509.

C_9 Group.

C_9H_8 Indene, determination of, 797.
C_9H_{10} Hydrindene, structure of, 1103.
α-Methylstyrene, polymerisation of, 1788.

9 II

$C_9H_8O_2$ Benzylglyoxal, 1915.
$C_9H_{10}O_2$ *p*-Ethylbenzoic acid, 1777.
$C_9H_{10}O_3$ 4-Methoxy-*o*-toluic acid, 264.
$C_9H_{10}O_4$ 2:4-Dihydroxy-6-ethoxybenzaldehyde, 289.
β-Methylsuberic acid, 1974.
$C_9H_{10}O_6$ 5-Carbomethoxy-2-keto-3-methyl-2:5-dihydrofuran-5-acetic acid, 1346.
$C_9H_{11}N$ 1-Methyldihydro*iso*indole, and its salts, 935.
$C_9H_{11}Cl$ β-*o*-Tolylethyl chloride, 395.
$C_9H_{12}O_3$ *C*-Methylphloroglucinol β-ethyl ether, 289.
$C_9H_{12}O_4$ α-Ethyl-γ-butyrolactone-β-pyruvaldehyde, 1064.
$C_9H_{12}O_6$ 3:3-Dimethyl*cyclo*butanetricarboxylic acid, 1341.
$C_9H_{14}O_2$ *cyclo*Hexane*spiro*butyrolactone, 1139.
β-*cyclo*Hexylidenepropionic acid, 1140.
β-2-Hydroxy*cyclo*hexylpropionolactone, 823.
$C_9H_{14}O_3$ β-Acetonyl-α-ethyl-γ-butyrolactones, 1062.
$C_9H_{14}O_5$ Methyl γ-keto-β-methyl-*n*-butane-αβ-dicarboxylate, 1346.
Methyl δ-keto-*n*-pentane-βγ-dicarboxylate, 1347.
$C_9H_{14}O_6$ 2:3:5-Trimethyl *l*-ascorbic acid, 833.
*iso*Trimethyl ascorbic acid, 834.
$C_9H_{14}O_7$ 2:3-Dimethyl *d*-gluco-ascorbic acid, 553.
*iso*Dimethyl gluco-ascorbic acid, 555.
$C_9H_{15}N$ 1-Methylhexahydropyrrocoline, and its picrolonate, 1522.
$C_9H_{16}O_2$ Δ^8-*n*-Nonenoic acid, 1974.
$C_9H_{16}O_3$ Ethyl β-tetrahydrofurylpropionate, 720.
8-Ketononoic acid, 722.
$C_9H_{17}N$ 1-Methyloctahydropyrrocoline, and its salts, 1522.
$C_9H_{17}Br$ Δ^8-*n*-Nonenyl bromide, 1974.
$C_9H_{18}O$ Δ^8-*n*-Nonenol, 1974.
$C_9H_{18}O_2$ Nordihydrocitronellic acid, 1591.
$C_9H_{18}O_6$ 4:6-Dimethyl β-methylglucoside, 1716.
Methyl 3:4:5-trimethyl *d*-arabonate, 554.
2:4:6-Trimethyl α-galactose, 1618.
2:3:6-Trimethyl glucopyranose, 1925.
3:4:6-Trimethyl α-*d*-mannose, 1925.

9 III

$C_9H_5N_3S_3$ Trithiocarbimidobenzenes, 1360.
$C_9H_6O_3N_2$ Acetylquinolinimide, 919.
$C_9H_7O_4N$ 6-Hydroxy-7-methoxyisatin, 402.
$C_9H_7O_4N_3$ 5-Nitro-1-methoxyphthalazone-4-one, 1845.
α- and β-Nitro-*N*-methylphthalaz-1:4-diones, 35.
$C_9H_8O_2N_2$ 3-Methylaminophthalimide, 589.
C_9H_9ON 3-Hydroxymethylindole, 1929.
$C_9H_9O_2N_3$ 5-Amino-1-methoxyphthalaz-4-one, 1845.
N-Amino-3-methylaminophthalimide, 589.
α- and β-Amino-*N*-methylphthalaz-1:4-diones, 35.
5-Methylaminophthalaz-1:4-dione, 589.
$C_9H_9NBr_2$ 4:6-Dibromo-5-aminohydrindene, 1107.
$C_9H_{10}O_2N_2$ Benzylglyoxime, 1915.
$C_9H_{10}O_3S$ 5:7-Dimethylbenzylsultone, 1351.
$C_9H_{10}O_4S$ Benzylsulphonylacetic acid, 315.
$C_9H_{10}NBr$ 4-Bromo-5-aminohydrindene, 1107.
$C_9H_{11}ON$ *m*-Dimethylaminobenzaldehyde, and its picrate, 1892.
$C_9H_{11}OCl$ β-*o*-Anisylethyl chloride, 1621.
$C_9H_{12}ON_2$ *m*-Dimethylaminobenzaldehyde oxime, 1892.
$C_9H_{12}O_2N_2$ 2-Methoxy-*m*-toluhydrazide, 261.
$C_9H_{12}O_4S$ *p*-2-Xylenol-5-methanesulphonic acid, salts, 1351.

$C_9H_{12}N_6S_3$ 1:2:4-Trithiocarbamidobenzene, 1360.
$C_9H_{13}O_{12}N_3$ 6-Acetyl β-methylglucoside 2:3:4-trinitrate, 1715.
$C_9H_{14}O_{10}N_2$ 4:6-Ethylidene β-methylglucoside 2:3-dinitrate, 1715.
$C_9H_{15}ON$ 2-Keto-octahydropyrrocoline, and its picrate, 1520.
l-4-*iso*Propyl-Δ^2-*cyclo*hexen-1-one oxime, 987.
$C_9H_{16}O_{10}N_2$ 4:6-Dimethyl β-methylglucoside 2:3-dinitrate, 1716.
$C_9H_{17}ON$ 1-Hydroxy-1-methyloctahydropyrrocoline, and its salts, 1522.
$C_9H_{17}O_2Br$ 9-Bromo-*n*-nonoic acid, 1979.
Ethyl 7-bromoheptoate, 722.
$C_9H_{18}O_6N_2$ 2:3:4-Trimethyl mannosaccharodiamide, 790.
$C_9H_{19}ON$ 1-Diethylaminopentan-3-one, 1578.
$C_9H_{19}O_5N$ 2:3:4:5-Tetramethylarabonamides, 554.
Trimethyl glucosamine, hydrochloride of, 1982.
$C_9H_{21}O_3Re$ Rhenium tri*iso*propoxide, 1408.

9 IV

$C_9H_8O_2NBr$ Bromonitrohydrindenes, 1107.
$C_9H_8O_3NI$ 2-Iodo-3-hydroxy-1-methyl-2:3-dihydroindole-5:6-quinone, 601.
C_9H_9OClS Phenyl *α-chloromethoxyvinyl sulphide*, 769.
$C_9H_9O_4BrHg$ 2-Bromomercuri-4-hydroxy-3:5-dimethoxybenzaldehyde, 853.
$C_9H_9O_5ClHg$ 2-Chloromercuri-4-*hydroxy-3:5-dimethoxybenzoic acid*, 853.
$C_9H_{10}ON_2S$ Acetyl-*o*-phenylenebisthioformamide, 363.
$C_9H_{10}O_2N_4S$ 1-Oxamyl-4-phenylthiosemicarbazide, 1361.
$C_9H_{10}O_4N_2Hg$ Nitroacetoxymercuritoluidines, 985.
$C_9H_{10}NCl_3S$ *S*-*p*-Dimethylaminophenyltrichloromethylthiol, 1632.
Methyl-*p*-toluidinotrichloromethylthiol, 1631.
$C_9H_{11}O_3NS$ *N*-Acetyl-*p*-toluenesulphonamide, 1118.
$C_9H_{12}ON_4S$ 2-Thion-*p*-tolyldiurea, 1361.
$C_9H_{16}O_4N_6S_3$ 3:5-Dithiomethanocarbonyldiurea, 1361.
$C_9H_{21}ClPAu$ Chlorotri-*n*-propylphosphinegold, 1832.

9 V

$C_9H_8O_4N_3Cl_3S$ Dinitro-*S*-*p*-dimethylaminophenyltrichloromethylthiol, 1633.
$C_9H_9NCl_3BrS$ Bromo-*S*-*p*-dimethylaminophenyltrichloromethylthiol, 1633.

C_{10} Group.

$C_{10}H_8$ Naphthalene, structure of, 1103.
$C_{10}H_{12}$ *α*-Dimethylstyrene, polymerisation of, 1790.
m-Propenyltoluene, 1760.
Tetrahydronaphthalene, structure of, 1103.
$C_{10}H_{16}$ 1-Δ^{γ}-Butenyl-Δ^1-*cyclo*hexene, 1138.
d-Limonene, rotation of, in various solvents, 151.
d-Pinene, rotation of, in various solvents, 149.
$C_{10}H_{18}$ *cis*-8-Methylhydrindane, 1145.

10 II

$C_{10}H_6N_2$ *o*-Cyanocinnamonitrile, 936.
$C_{10}H_6Br_2$ 2:3-Dibromonaphthalene, 1529.
$C_{10}H_8O_3$ Trihydroxynaphthalenes, 1861.
$C_{10}H_8O_4$ 7-Hydroxy-5-methoxycoumarin, 293.
$C_{10}H_{10}O_3$ *γ*-Phenoxycrotonic acid, 1060.
$C_{10}H_{12}O_2$ *p*-*iso*Propylbenzoic acid, 1777.
$C_{10}H_{12}O_3$ 2-Methoxy-*m*-tolylacetic acid, 261.
4-Methoxy-*o*-tolyl acetic acid, 265.
4-Methoxy-*m*-tolylacetic acid, 263.
5-Methoxy-*o*-tolylacetic acid, 512.
$C_{10}H_{12}O_4$ 2:6-Dihydroxy-4-ethoxy-3-methylbenzaldehyde, 289.
2-Hydroxy-4:6-dimethoxy-5-methylbenzaldehyde, 288.
$C_{10}H_{13}N$ Tetrahydrobenzoquinaldine, and its salts, 1529.
$C_{10}H_{13}Cl$ *p*-Tolylethylchloromethane, 1758.
$C_{10}H_{14}O$ 5-Ketomethyl-$\Delta^{4:9}$-tetrahydrohydrindenes, 59.
2-Keto-$\Delta^{1:9}$-octalin, 56.
$C_{10}H_{14}O_6$ Methyl 1:2-diacetylsuccinate, 925.
$C_{10}H_{15}N$ Thymylamine, oxalate of, 1596.
$C_{10}H_{15}N_3$ Triallylguanidine, hydrochloride of, 828.
$C_{10}H_{16}O$ Campholic aldehyde, rotatory dispersion of, 233.
8-Methyl-1-hydrindanone, 816, 1161.
cis-8-Methyl-2-hydrindanone, 1144.
$C_{10}H_{16}O_2$ 3-Hydroxy-*cis*-2-decalone, 824.
$C_{10}H_{16}O_4$ *cis*-*β*-Ethoxymethyl-*α*-ethylglutaric anhydride, 1062.
Δ^4-*n*-Heptenylmalonic acid, 1974.
Homocaryophyllenic acid, structure of, 73.

$C_{10}H_{16}O_6$ Jaconecic acid, 585.
$C_{10}H_{17}N$ Ethylhexahydropyrrocolines, and their picrolonates, 1521.
$C_{10}H_{18}O$ 1-Δ^{γ}-Butenyl*cyclo*hexanol, 1138.
Carvotanacetols, 239.
dl-Δ^6-*neo*Menthen-3-ol, 238.
$C_{10}H_{18}O_3$ 9-Ketodecoic acid, 723.
$C_{10}H_{18}O_5$ β-Ethoxymethyl-α-ethylglutaric acids, 1062.
$C_{10}H_{19}N$ Carvotanacetylamines, and their salts, 241.
1-Ethyloctahydropyrrocoline, 1521.
2-Ethyloctahydropyrrocoline, and its salts, 1521.
2-Methyloctahydropyridocoline, and its picrate, 1522.
$C_{10}H_{20}O$ *cis*-8-Hydroxy-*p*-menthane, preparation of, 2007.
$C_{10}H_{20}O_2$ *dl*-Menthane-1:3-diols, 238.
$C_{10}H_{20}O_6$ Methyl 2:3:4:5-tetramethyl *d*-arabonate, 554.
2:3:4:6-Tetramethyl glucose, 1924.
2:3:6-Trimethyl methylglucopyranoside, 1925.

10 III

$C_{10}H_4N_2S$ 2:3-Dicyanothionaphthen, 918.
$C_{10}H_5O_5N$ Nitrohydroxy-1:2-naphthaquinones, 1862.
$C_{10}H_6O_2Br_2$ 1:5-Dibromo-2:6-dihydroxynaphthalene, 1861.
$C_{10}H_6O_4N_4$ Pyromellitaz-1:4:6:9-tetraone, and its sodium salt, 591.
$C_{10}H_6ClBr$ 1-Chloro-2-bromonaphthalene, 1352.
$C_{10}H_7O_5N$ 8-Nitro-1:2:7-trihydroxynaphthalene, 1862.
$C_{10}H_8O_2N_2$ *iso*Carbostyril-3-carboxylamide, 475.
$C_{10}H_8O_2S$ Thionaphthen-2-acetic acid, 1698.
$C_{10}H_8O_3N_2$ *N*-Acetamidophthalimide, 21.
Acetylphthalaz-1:4-dione, 25.
$C_{10}H_8O_4S_2$ 2-Hydroxynaphthyl-1-thiolsulphonic acid, sodium salt, 1351.
$C_{10}H_8NBr$ 3-Bromo-β-naphthylamine, 1529.
$C_{10}H_8N_2S$ 6-Thioformamidoquinoline, 363.
$C_{10}H_9O_3N$ 8-Amino-1:2:7-trihydroxynaphthalene, 1862.
$C_{10}H_9O_3N_3$ 3-Acetamido-*N*-aminophthalimide, 1843.
Acetamidophthalaz-1:4-diones, 30.
$C_{10}H_9O_4N_3$ 5-Nitro-1:4-dimethoxyphthalazine, 1846.
Nitro-*N*-dimethylaminophthalimides, 35.
Nitro-2:3-dimethylphthalaz-1:4-diones, 35.
Nitromethoxymethylphthalazones, 1844.
$C_{10}H_9O_4Br$ Methyl 2-bromoisophthalate, 1305.
$C_{10}H_9N_3S$ 2-Keto-2:3-dihydrothiazole-2-benzylidenehydrazone, 559.
$C_{10}H_{10}O_2N_2$ 1:4-Dimethoxyphthalazine, 1845.
N-Dimethylaminophthalimide, 35.
2:3-Dimethylphthalaz-1:4-dione, 35.
$C_{10}H_{10}O_4N_4$ 6-Hydroxy-7-methoxyisatin semicarbazone, 402.
$C_{10}H_{11}ON$ 3-Methoxymethylindole, 1928.
$C_{10}H_{11}O_2N$ β-Hydroxy-γ-phenoxybutyronitrile, 1061.
$C_{10}H_{11}O_2N_3$ 5-Amino-1:4-dimethoxyphthalazine, 1846.
Amino-2:3-dimethylphthalaz-1:4-diones, 36.
Aminomethoxymethylphthalazones, 1844.
$C_{10}H_{11}O_2Na$ Sodium eugenoxide, reaction of, with alkyl iodides, 1172.
$C_{10}H_{11}O_3N$ Ethyl hydroxymethylene-2-pyridylacetate, 967.
$C_{10}H_{12}O_2N_2$ Ethyl 5-cyano-2:3-dimethylpyrrole-4-carboxylate, 927.
$C_{10}H_{13}OCl$ β-(4-Methoxy-*o*-tolyl)ethyl chloride, 265.
β-(5-Methoxy-*o*-tolyl)ethyl chloride, 511.
$C_{10}H_{13}O_2N$ 2-Cyano-1:3-dimethyl-1:3-*cyclo*hexanolide, 259.
$C_{10}H_{13}O_2N_3$ 4-Methoxy-*o*-tolualdehyde semicarbazone, 265.
$C_{10}H_{13}O_4N$ Ethyl 3:5-dihydroxyphenylaminoacetate, 455.
5-Nitro-4-ethylveratrole, 431.
$C_{10}H_{14}ON_4$ *m*-Dimethylaminobenzaldehyde semicarbazone, 1892.
$C_{10}H_{14}O_2N_2$ *r*-Pilocarpidines, 1064.
$C_{10}H_{14}NBr$ Bromoaminodurene, 14.
$C_{10}H_{15}ON_3$ 3-Ketodecahydro*peri*pyridazopyridocoline, 967.
$C_{10}H_{15}OCl$ 3-Chloro-*cis*-2-decalone, 824.
$C_{10}H_{17}ON$ 1-Hydroxy-1-ethylhexahydropyrrocoline, 1521.
1-Keto-2-methyloctahydropyridocoline, and its salts, 1522.
2-Keto-1-methyloctahydropyridocoline, and its salts, 968.
$C_{10}H_{17}ON_3$ Ethyl 2-keto-$\Delta^{1:9}$-octalin-10-carboxylate semicarbazone, 56.
$C_{10}H_{17}O_2N$ Acetyltropeïne, and its hydrobromide, 1822.
$C_{10}H_{17}O_3N_3$ β-Acetonyl-α-ethyl-γ-butyrolactone semicarbazones, 1062.
β-2-Keto*cyclo*hexylpropionic acid semicarbazone, 823.
$C_{10}H_{17}O_3As$ Camphor-10-arsinic acid, 392.
$C_{10}H_{17}O_4As$ Camphor-10-arsonic acid, 392.
$C_{10}H_{17}O_5N_3$ Methyl γ-keto-β-methyl-*n*-butane-αβ-dicarboxylate semicarbazone, 1346.
$C_{10}H_{18}O_7S$ α-Carbethoxyethyl sulphite, 158.

$C_{10}H_{18}NBr$ 1-Bromomethyloctahydropyridocoline, and its salts, 969.
$C_{10}H_{19}ON$ 2-Hydroxy-2-ethyloctahydropyrrocoline, and its picrolonate, 1520.
1-Octahydropyridocolylcarbinols, and their salts, 969.
$C_{10}H_{19}O_3N_3$ 8-Ketononoic acid semicarbazone, 723.
$C_{10}H_{20}O_5S$ α-Carbethoxyethyl *n*-amyl sulphite, 158.
$C_{10}H_{21}O_5N$ Trimethyl α-methylglucosaminide, and its hydrochloride, 1983.
$C_{10}H_{22}O_3S$ *n*-Amyl sulphite, 158.

10 IV

$C_{10}H_5O_2NI_2$ Di-iodonitronaphthalenes, 124.
$C_{10}H_5O_2NS$ Thionaphthen-2:3-dicarboxyimide, 917.
$C_{10}H_5O_4N_2I$ 1-Iodo-4:8-dinitronaphthalene, 572.
$C_{10}H_6ON_2S$ Cyanothionaphthenecarboxyamide, 918.
$C_{10}H_6O_2NBr$ 1-Bromo-2-*o*-cyanophenylacrylic acid, 936.
Bromonitronaphthalenes, 1106.
$C_{10}H_6O_2NI$ 1-Iodo-8-nitronaphthalene, 572.
$C_{10}H_7O_2NBr_2$ *o*-Cyanophenylacetylene, 936.
$C_{10}H_8O_2N_2S$ Thionaphthen-2:3-dicarboxyamide, 917.
$C_{10}H_9N_2ClS$ 2-*o*-Chlorobenzylaminothiazole, hydrochloride of, 962.
$C_{10}H_{10}ONCl$ β-Chloro-γ-phenoxybutyronitrile, 1061.
$C_{10}H_{10}O_2NBr$ Bromonitrotetralins, 1107.
6-Bromoveratrylacetonitrile, 840.
$C_{10}H_{11}O_2ClS$ γ-Chloro-α-benzylsulphonyl-Δ^{α}-propylene, 312.
$C_{10}H_{11}O_2BrS$ γ-Bromo-α-benzylsulphonylpropylenes, 312.
$C_{10}H_{11}O_5BrHg$ 2-Bromomercuri-3:4:5-trimethoxybenzoic acid, 853.
$C_{10}H_{12}O_2Cl_2S$ βγ-Dichloro-α-benzylsulphonylpropane, 312.
$C_{10}H_{12}O_2Br_2S$ βγ-Dibromo-α-benzylsulphonylpropane, 311.
$C_{10}H_{13}OClS$ γ-Chloro-β-hydroxy-α-benzylthiopropane, 313.
$C_{10}H_{13}O_3NS$ *N*-Acetyl-*p*-toluenesulphonmethylamide, 1118.
$C_{10}H_{13}O_3N_3S$ Triacetyl-2-amino-5-methyl-1:3:4-thiadiazine, 558.
$C_{10}H_{13}O_3ClS$ γ-Chloro-β-hydroxy-α-benzylsulphonylpropane, 313.
$C_{10}H_{13}O_4NS$ *N*-Acetyl-*N*-methyl-*p*-toluidine-3-sulphonic acid, brucine and sodium salts, 276.
m-Xylene-4-sulphonylglycine, 1696.
$C_{10}H_{13}N_4ClS$ 3-(4′-Amino-2′-methylpyrimidyl-5′-methyl)-4-methylthiazolium chloride, hydrochloride of, 1506.
$C_{10}H_{15}OCl_2As$ Camphor-10-dichloroarsine, 392.

10 V

$C_{10}H_{12}ON_3ClS$ 3-(4′-Hydroxy-2′-methylpyrimidyl-5′-methyl)-4′-methylthiazolium chloride, hydrochloride of, 1507.
$C_{10}H_{14}O_2NClS$ *p*-Toluenesulphon-γ-chloropropylamide, 1470.
$C_{10}H_{14}O_4NClS$ *N*-Chloropyridinium *N*-α-carbethoxyethylsulphinate, 157.

C_{11} Group.

$C_{11}H_{18}$ 1-Methyloctalin, 1151.
cis-9-Methyloctalin, 1145.
$C_{11}H_{20}$ 1-Methyldecalin, 1151.
cis-9-Methyldecalin, 1145.

11 II

$C_{11}H_6N_4$ 4:5-Dicyano-2-phenyliminazole, 1437.
$C_{11}H_8O_3$ 7-Methoxy-1:2-naphthaquinone, 1861.
$C_{11}H_8O_4$ 4:8-Dihydroxy-1-naphthoic acid, 940.
$C_{11}H_8O_5$ Piperonyltetronic acid, 1649.
$C_{11}H_8O_6$ 7-Hydroxy-5-methoxycoumarin-3-carboxylic acid, 293.
$C_{11}H_8N_4$ Benzylideneaminoiminosuccinonitrile, 1436.
Salicylideneaminoiminosuccinonitrile, 1436.
$C_{11}H_{10}O$ 2-Methylene-α-tetralone, 1170.
$C_{11}H_{10}O_2$ Phenoxypropynyl methyl ketone, 1063.
$C_{11}H_{10}O_3$ 1:2-Dihydroxy-7-methoxynaphthalene, 1861.
$C_{11}H_{10}O_4$ 7:8-Ethylenedioxychromanone, 50.
$C_{11}H_{12}O_2$ 5-Acetoxyhydrindene, 478.
5-Hydroxyacetylhydrindenes, 478.
$C_{11}H_{12}O_3$ *p*-Acetoxypropiophenone, 455.
γ-Benzoyl-*n*-butyric acid, 1015.
$C_{11}H_{12}O_4$ 5:7-Dihydroxy-2:2-dimethylchromanone, 284.
4:6-Dihydroxy-2-*iso*propyl-3-coumaranone, 285.
2-Methoxy-*m*-tolylpyruvic acid, 261.
$C_{11}H_{12}O_5$ 2:3-Ethylenedioxy-β-phenoxypropionic acid, 50.
$C_{11}H_{14}O$ 2-Allyl-*p*-tolyl methyl ether, 265.
3-Allyl-*o*-tolyl methyl ether, 262.
6-Allyl-*m*-tolyl methyl ether, 512.
γ-Phenyl-α-methylallyl methyl ethers, 217.

$C_{11}H_{14}O_2$ 7-Hydroxy-2:2-dimethylchroman, 1532.
$C_{11}H_{14}O_3$ 5:7-Dihydroxy-2:2-dimethylchroman, 283.
2:6-Dihydroxy*iso*valerophenone, 278.
3-*iso*Propyl-Δ^4-tetrahydrophthalic anhydride, 1074.
$C_{11}H_{16}O$ 2-Ketomethyl-$\Delta^{1:9}$-octalins, 58.
2-Methyl-$\Delta^{9:10}$-1-octalone, 822.
$C_{11}H_{16}O_2$ Tetrahydrotubanol, 278.
$C_{11}H_{17}N$ *p*-Amino-*n*-amylbenzene, and its hydrochloride, 1120.
$C_{11}H_{18}O$ 2-Keto-10-methyldecalin, 59.
2-Methyl-1-decalone, 822.
cis-9-Methyl-2-decalone, 1143.
$C_{11}H_{18}O_2$ γ-Δ^1-*cyclo*Hexenyl-α-methylbutyric acid, 822.
$\Delta^{9:10}$-Undecynoic acid, hydration of, 1501.
$C_{11}H_{18}O_4$ *cis*-1-Methyl*cyclo*hexane-1:2-diacetic acid, 1144.
$C_{11}H_{18}O_6$ Octane-$\alpha\delta\theta$-tricarboxylic acid, 821.
$C_{11}H_{20}O$ 1-Methy'-1-decalol, 1151.
cis-9-Methyl-2-decalol, 1143.
$C_{11}H_{20}O_2$ Δ^{10}-*n*-Undecenoic acid, synthesis of, 1971.
$C_{11}H_{20}O_3$ Ethyl 8-ketononoate, 723.
9-Ketoundecoic acid, 950.
$C_{11}H_{20}O_4$ β-Methylsebacic acid, 1978.
$C_{11}H_{22}O_3$ 9-Hydroxyundecoic acid, 951.
$C_{11}H_{22}O_6$ Tetramethyl methylglucopyranoside, 1924.

11 III

$C_{11}H_7O_2Br$ 3-Bromo-1-naphthoic acid, 1767.
3-Bromo-2-naphthoic acid, 1528.
$C_{11}H_9O_3N$ 2-Carbomethoxyindole-3-aldehyde, 469.
Methyl *iso*carbostyril-3-carboxylate, 475.
$C_{11}H_9O_4Br$ Butyl bromomalonates, 1811.
$C_{11}H_9O_3N_3$ Acetylnitromethylphthalaz-1:4-diones, 35.
$C_{11}H_{10}O_2N_2$ *N*-*iso*Propylideneaminophthalide, 21.
$C_{11}H_{10}O_3N_2$ 3-*N*-Acetyl-3-methylaminophthalimide, 589.
$C_{11}H_{10}O_4N_4$ 5-Acetcarbamidophthalaz-1:4-dione, 1843.
$C_{11}H_{11}O_3Br$ 6-Bromo-5-acetoxyhydrindene, 478.
6-Bromo-5-hydroxy-4-acetylhydrindene, 478.
$C_{11}H_{11}O_3N_3$ 5-Acetamido-2-methylphthalaz-1:4-dione, 1846.
5-*N*-Acetylmethylaminophthalaz-1:4-dione, 589.
*cyclo*Pentane-1:2-dione *p*-nitrophenylhydrazone, 811.
$C_{11}H_{11}O_3Cl$ Chloromethyl α-acetoxybenzyl ketone, 1914.
$C_{11}H_{11}N_3S$ 2-Keto-4-methyl-2:3-dihydrothiazole-2-benzylidenehydrazone, and its hydrochloride, 557.
$C_{11}H_{12}O_2N_2$ *N*-Ethylglycinephenylhydantoin, 1694.
N-Methylalaninephenylhydantoin, 1695.
$C_{11}H_{12}N_2S$ Thioformyltryptamine, 363.
$C_{11}H_{12}N_4S_2$ 2-Anilinothioformamido-5-methyl-1:3:4-thiadiazine, 558.
$C_{11}H_{13}ON$ 3-Ethoxymethylindole, 1929.
$C_{11}H_{13}O_2N$ 5-Cyano-4-ethylveratrole, 431.
$C_{11}H_{13}O_3N$ Benzoyl-*N*-methylalanine, 1695.
*iso*Propyl hydroxymethylene-2-pyridylacetate, 967.
$C_{11}H_{13}O_3N_3$ 7-Methoxychromanone semicarbazone, 1534.
$C_{11}H_{13}O_4N_3$ ω-Aldehydovaleric acid *o*-nitrophenylhydrazone, 811.
$C_{11}H_{14}O_2N_2$ Trimethylethylene nitrosoketoanilide, 375.
$C_{11}H_{14}O_4S$ Ethyl benzylsulphonylacetate, 315.
$C_{11}H_{15}ON$ 4-*iso*Propylacetanilide, 1595.
$C_{11}H_{15}OBr$ 5-Phenoxy-*n*-amyl bromide, 1976.
$C_{11}H_{15}O_2Cl$ 4:5-Dimethoxy-2-ethylbenzyl chloride, 431.
$C_{11}H_{16}O_2N_2$ *r*-Pilocarpine, resolution of, 1064.
$C_{11}H_{16}O_{12}N_2$ 2:3-Diacetyl β-methylglucoside 4:6-dinitrate, 1717.
4:6-Diacetyl β-methylglucoside 2:3-dinitrate, 1716.
$C_{11}H_{17}ON$ 2-Methyl-$\Delta^{9:10}$-1-octalone oxime, 822.
$C_{11}H_{17}ON_3$ 5-Ketomethyl-$\Delta^{4:9}$-tetrahydrohydrindene semicarbazones, 59.
$C_{11}H_{17}O_2N$ *m*-Aminobenzaldehyde diethylacetal, 1891.
4:5-Dimethoxy-2-ethylbenzylamine, and its picrolonate, 431.
$C_{11}H_{17}O_3N$ Ethyl 1-keto-octahydropyrrocoline-2-carboxylate, 1523.
Ethyl 3-keto-octahydropyrrocoline-1-carboxylate, 968.
$C_{11}H_{18}O_4Br_2$ Butyl dibromomalonates, 1811.
$C_{11}H_{19}ON$ Methyl-1-decalone oximes, 822.
2-Methyl-5-diethylaminomethyl*cyclo*pentanone, 59.
$C_{11}H_{19}ON_3$ 8-Methyl-1-hydrindanone semicarbazone, 816, 1161.
cis-8-Methyl-2-hydrindanone semicarbazone, 1144.
$C_{11}H_{19}O_2N$ 2-Methyl*cyclo*pentanone-3-carboxydiethylamide, 1589.
$C_{11}H_{19}O_3N_3$ γ-Benzoyl-$\beta\beta$-dimethyl-*n*-butyric acid semicarbazone, 1015.
$C_{11}H_{19}O_4N$ 3-Carboxy-2:2:5:5-tetramethylpyrrolidine-1-acetic acid, 1525.

$C_{11}H_{21}O_2N_3$ *dl*-1-Hydroxymenthone semicarbazone, 237.
$C_{11}H_{21}O_2Br$ Bromoundecoic acids, 951.
$C_{11}H_{21}O_3N_3$ 9-Ketodecoic acid semicarbazone, 723.

11 IV

$C_{11}H_7ON_4Br$ *m*-Bromosalicylideneaminoiminosuccinonitrile, 1436.
$C_{11}H_8O_3NI$ Phthalo-ω-iodoacetonylimide, 1167.
$C_{11}H_9ON_2Br$ 3-Bromo-2-naphthoic hydrazide, 1528.
$C_{11}H_9ON_3S_3$ 3:4-Dithiocarbamidophenylthiourethane, 1360.
$C_{11}H_{11}NCl_2S$ *N*-*o*-Chlorobenzyl-4-methylthiazolium chloride, 962.
$C_{11}H_{11}N_2ClS$ 2-*o*-Chlorobenzylamino-4-methylthiazole, hydrochloride of, 962.
$C_{11}H_{12}NClS$ *N*-Benzyl-4-methylthiazolium chloride, 962.
$C_{11}H_{12}NIS$ *N*-*o*-Tolyl-4-methylthiazolium iodide, 962.
$C_{11}H_{14}NCl_3S$ *p*-Diethylaminophenyltrichloromethylthiol, 1633.
$C_{11}H_{14}N_2Cl_2S$ *N*-*o*-Aminobenzyl-4-methylthiazolium chloride, 962.
$C_{11}H_{14}N_2I_2S$ *N*-*o*-Aminobenzyl-4-methylthiazolium iodide, 962.
$C_{11}H_{15}O_4NS$ Mesitylenesulphonylglycine, 1696.
m-Xylene-4-sulphonylsarcosine, 1696.
$C_{11}H_{15}NClBr$ *p*-Chlorophenyldimethylallylammonium bromide, 615.
$C_{11}H_{15}NBrI$ *p*-Iodophenyldimethylallylammonium bromide, 615.
$C_{11}H_{15}NBrF$ *p*-Fluorophenyldimethylallylammonium bromide, 615.

11 V

$C_{11}H_{11}O_2N_2ClS$ *N*-*o*-Nitrobenzyl-4-methylthiazolium chloride, 962.
$C_{11}H_{16}O_2NClS$ *p*-Toluenesulphon-(β-chloroethyl)ethylamide, 1470.

C_{12} Group.

$C_{12}H_{12}$ 1:8-Dimethylnaphthalene, 1156.
$C_{12}H_{16}$ 2:2-Dimethyltetralin, 257.
$C_{12}H_{20}$ 1:10-Dimethyloctalin, 1145.
$C_{12}H_{22}$ 1:10-Dimethyldecalin, 1145.

12 II

$C_{12}H_8O_4$ Bergapten, structure and synthesis of, 293.
$C_{12}H_{10}O_4$ 1-Hydroxy-5-methoxy-2-naphthoic acid, 940.
$C_{12}H_{11}N_3$ Diazoaminobenzene, dipole moment of, 1808.
$C_{12}H_{12}O_4$ 5:7-Dimethoxy-6-methylcoumarin, 288.
$C_{12}H_{12}O_5$ Veratryltetronic acid, 1649.
$C_{12}H_{12}O_6$ Veratroylpyruvic acid, 1648.
$C_{12}H_{14}O$ 2:2-Dimethyl-1-tetralone, 257.
4:5-Dimethyl-1-tetralone, 1156.
$C_{12}H_{14}O_2$ 7-Hydroxy-2:2:4-trimethyl-Δ^3-chromen, 1534.
α-Phenyl-γ-methylallyl acetates, 215.
$C_{12}H_{14}O_3$ Acid, from oxidation of anisoxide, 515.
β-Benzoyl-αα-dimethylpropionic acid, 256.
Ethyl γ-phenoxycrotonate, 1059.
7-Hydroxy-6-formyl-2:2-dimethylchroman, 1544.
6-Methoxy-2-*iso*propyl-β-coumaranone, 1533.
$C_{12}H_{14}O_4$ 5:7-Dihydroxy-8-formyl-2:2-dimethylchroman, 290.
5-Hydroxy-7-methoxy-2:2-dimethylchromanone, 1539.
7-Hydroxy-5-methoxy-2:2-dimethylchromanone, 1539.
$C_{12}H_{14}O_5$ γ-(2-Carboxy-5-methoxyphenyl)butyric acid, 71.
$C_{12}H_{14}O_6$ Ethyl quinol-2:3-dicarboxylate, 483.
Veratrylsuccinic acid, 836.
$C_{12}H_{14}O_8$ Methyl 2-keto-3-methyl-2:5-dihydrofuran-5-malonate-5-carboxylate, 1345.
$C_{12}H_{16}O$ Cuminyl methyl ketone, 763.
$C_{12}H_{16}O_2$ β-Benzyl-αα-dimethylpropionic acid, 256.
Methyl δ-phenoxybutyl ketone, 724.
$C_{12}H_{16}O_3$ β-Asarone, 1338.
7-Hydroxy-5-methoxy-2:2-dimethylchroman, 1540.
$C_{12}H_{16}O_4$ Ethyl *p*-hydroxy-γ-phenoxybutyrate, 1061.
α-3-Methoxyphenoxy*iso*valeric acid, 1534.
$C_{12}H_{17}O_3$ 5-Hydroxy-7-methoxy-2:2-dimethylchroman, 1539.
$C_{12}H_{18}O$ *1:6-Dimethyl-$\Delta^{9:10}$-4-octalone, 823.*
$C_{12}H_{18}O_4$ β-Δ^1-*cyclo*Hexenylethylmethylmalonic acid, 822.
$C_{12}H_{18}O_5$ *cyclo*Hexanone-2:6-ββ′-dipropionic acid, 946.
α-2:4:5-Trimethoxyphenyl-β-methylethylene glycol, 1340.
$C_{12}H_{18}S_2$ γ-Benzylthio-α-ethylthiopropane, 314.
$C_{12}H_{19}N$ *p*-Amino-*n*-hexylbenzene, and its salts, 1121.
n-Hexylaniline, and its hydrobromide, 1121.
$C_{12}H_{20}O_2$ γ-(4-Methyl-Δ^1-*cyclo*hexenyl)valeric acid, 823.
$C_{12}H_{20}O_3$ Ethyl γ-2-keto*cyclo*hexylbutyrate, 821.

$C_{12}H_{20}O_4$ ββ′-Bistetrahydrofuryl*iso*butyric acid, 720.
Methyl 2-carbomethoxy-1:1-dimethyl*cyclo*butane-3-β-propionate, 75.
Methyl *dl*-2-carbomethoxymethyl-1:1-dimethyl*cyclo*butane-3-acetate, 75.
Methyl homocaryophyllenate, 75.
Δ[8]-*n*-Nonenylmalonic acid, 1974.
$C_{12}H_{20}O_5$ Ethyl tetrahydrofurfurylmalonate, 719.
$C_{12}H_{20}O_7$ Gluconic acid diacetone, 796.
$C_{12}H_{22}O$ 2:6-Dimethyl-1-Δ^γ-butenyl*cyclo*hexanol, 1145.
$C_{12}H_{22}O_2$ Dihydrocitronellylideneacetic acids, 1590.
$C_{12}H_{22}O_3$ Menthane-1:3-diol acetate, 238.
$C_{12}H_{22}O_7$ Pentamethyl gluco-ascorbic acid, 553.

12 III

$C_{12}H_2O_2Br_4$ Tetrabromoacenaphthenequinone, 1762.
$C_{12}H_3O_2Br_3$ Tribromoacenaphthenequinone, 1762.
$C_{12}H_3O_3Br_3$ Tribromonaphthalic anhydride, 1766.
$C_{12}H_5O_3Br$ 3-Bromonaphthalic anhydride, 1765.
$C_{12}H_5O_4N_2$ α-Methyl-lævulic acid *p*-nitrophenylhydrazone, 1346.
$C_{12}H_6NCl_5$ 2:4:6:2′:4′-Pentachlorodiphenylamine, 1956.
$C_{12}H_8O_2N_2$ Norharmancarboxylic acid, 472.
$C_{12}H_8O_2Br$ Methyl 3-bromo-1-naphthoate, 1767.
$C_{12}H_8O_2Br_2$ Methyl 1:6-dibromo-2-naphthoate, 1103.
$C_{12}H_8O_3N_2$ 2-Keto-2:3-dihydro-β-carboline-4-carboxylic acid, 470.
$C_{12}H_8O_4N_2$ 2-Phenylpyrimidine-4:6-dicarboxylic acid, 495.
$C_{12}H_8NCl$ 4-Chlorocarbazole, 1128.
$C_{12}H_8NCl_3$ 2:4:4′-Trichlorodiphenylamine, 1955.
$C_{12}H_9O_2N$ *p*-Nitrodiphenyl sulphide, compounds of, with sulphuric acid, 1634.
$C_{12}H_9O_2Br$ Bromo-3-acetyl-2-naphthol, 482.
Methyl 3-bromo-β-naphthoate, 1528.
$C_{12}H_9O_3N$ *p*-Nitrodiphenyl ether, compounds of, with sulphuric acid, 1634.
$C_{12}H_9NCl_2$ 2:4′-Dichlorodiphenylamine, 1955.
$C_{12}H_9NS_2$ 2-Aminothianthren, 1592.
$C_{12}H_{10}ON_2$ *p*-Hydroxyazobenzene, dipole moment of, 1858.
$C_{12}H_{10}ON_4$ Anisylideneaminoiminosuccinonitrile, 1436.
$C_{12}H_{10}O_2N_2$ 2-Phenyl-4-methylpyrimidine-6-carboxylic acid, 495.
$C_{12}H_{10}O_2Br_2$ 1:5-Dibromo-2:6-dimethoxynaphthalene, 1861.
$C_{12}H_{10}O_4N_2$ 4-Acetoxy-2-acetylphthalaz-1-one, 25.
$C_{12}H_{10}O_5N_2$ 3:6-Diacetamidophthalic anhydride, 590.
$C_{12}H_{10}O_6N_2$ 1:5-Dinitro-2:6-dimethoxynaphthalene, 1860.
$C_{12}H_{10}NCl$ 12-Chloro-2:3-dihydro-β-quinindene, 377.
$C_{12}H_{10}N_2Cl_2$ 4:4-Dichlorodiaminodiphenyls, 38.
2:4′-Dichloro-*NN*-diphenylhydrazine, 1956.
$C_{12}H_{11}O_3N$ 4-Acetyl-2-methylhomophthalimide, 1313.
Ethyl *iso*carbostyril-3-carboxylate, 475.
Methyl 1-keto-2-methyl-1:2-dihydroisoquinoline-3-carboxylate, 475.
$C_{12}H_{11}O_4N$ 1-Nitro-2:6-dimethoxynaphthalene, 1860.
$C_{12}H_{11}O_4N_3$ 3:6-Diacetamidophthalimide, 589.
$C_{12}H_{11}N_2Cl$ *N*-Phenyl-*N*-*p*-chlorophenylhydrazine, 1956.
$C_{12}H_{11}N_5Cl_4$ Bis-(2:4-dichloro-6-methylpyrimidyl-5-methyl)amine, 1509.
$C_{12}H_{12}ON_2$ 1-Phenyl-3:4-*cyclo*pentano-5-pyrazolone, 810.
$C_{12}H_{12}O_4N_4$ *N*-Amino-3:6-diacetamidophthalimide, 590.
5:8-Diacetamidophthalaz-1:4-dione, 590.
$C_{12}H_{12}O_8N_4$ α-Ketoadipic acid 2 : 4-dinitrophenylhydrazone, 811.
$C_{12}H_{12}NCl$ Chlorotetrahydrocarbazoles, 1127.
$C_{12}H_{13}O_2N$ 1-Aminodimethoxynaphthalenes, 1860.
$C_{12}H_{13}O_2N_3$ Phenoxypropynyl methyl ketone semicarbazone, 1063.
$C_{12}H_{13}O_3N_3$ Acetamido-2:3-dimethylphthalaz-1:4-diones, 36.
5-*N*-Acetylaminomethoxymethylphthalazones, 1844.
$C_{12}H_{13}N_2Cl$ 6-Chloro-7-aminotetrahydrocarbazole, 1128.
$C_{12}H_{13}N_3S$ 2-Keto-4-methyl-2:3-dihydrothiazole-2-α-phenylethylidenehydrazone, and its hydrochloride, 557.
$C_{12}H_{14}ON_2$ 6-Keto-3-phenyl-5:5-dimethyltetrahydropyridine, 256.
$C_{12}H_{14}O_2N_2$ Diaminodimethoxynaphthalenes, 1860.
$C_{12}H_{14}O_6Hg$ 2-Acetoxymercuri-3:4:5-trimethoxybenzaldehyde, 853.
$C_{12}H_{14}NCl$ 6-Chlorohexahydrocarbazole, 1128.
$C_{12}H_{15}O_2N_3$ *oo*′-Dimethoxydiazoaminobenzene, 324.
$C_{12}H_{15}O_3N$ Benzoyl-*N*-propylglycine, 1694.
$C_{12}H_{15}O_3N_3$ γ-Benzoyl-*n*-butyric acid semicarbazone, 1015.
$C_{12}H_{15}O_3Cl$ Ethyl β-chloro-γ-phenoxybutyrate, 1061.
$C_{12}H_{15}O_3Br$ Ethyl α-bromo-γ-phenoxybutyrate, 1059.
$C_{12}H_{15}O_4N_3$ Methyl lævulate *p*-nitrophenylhydrazone, 1618.
$C_{12}H_{16}O_3N_2$ Trimethylethylene nitrosoketo-*p*-toluidide, 375.
$C_{12}H_{16}O_2S_2$ α-Benzylsulphonyl-γ-ethylthiopropylene, 312, 313.
γ-Benzylthio-α-ethylsulphonyl-Δ^α-propylene, 314.

$C_{12}H_{16}O_4N_4$ *sec.*-Butylacetaldehyde 2:4-dinitrophenylhydrazone, 1045.
Diethylacetaldehyde 2:4-dinitrophenylhydrazone, 1046.
Dimethylethylacetaldehyde 2:4-dinitrophenylhydrazone, 1046.
dl-Methyl*iso*propylacetaldehyde 2:4-dinitrophenylhydrazone, 1045.
$C_{12}H_{16}O_4S$ Ethyl α-*p*-toluenesulphinoxypropionate, 156.
Tetrahydrofurfuryl *p*-toluenesulphonate, 720.
$C_{12}H_{16}O_4S_2$ α-Benzylsulphonyl-γ-ethylsulphonylpropylenes, 312.
$C_{12}H_{16}O_6N_4$ γ-Keto-β-hydroxymethyl-β-methylbutyl alcohol 2:4-dinitrophenylhydrazone, 843.
$C_{12}H_{17}O_2N_3$ Trimethylethylene nitrosonitrol-*o*-toluidide, 375.
$C_{12}H_{17}O_3N$ 5-Amino-4-ethylveratrole, 431.
$C_{12}H_{17}ClS_2$ β-Chloro-α-benzylthio-γ-ethylthiopropane, 314.
$C_{12}H_{18}OS_2$ β-Hydroxy-α-benzylthio-γ-ethylthiopropane, 314.
$C_{12}H_{18}O_3S_2$ β-Hydroxy-γ-benzylthio-α-ethylsulphonylpropane, 313.
β-Hydroxy-γ-ethylthio-α-benzylsulphonylpropane, 313.
$C_{12}H_{18}O_4S_2$ γ-Benzylsulphonyl-α-ethylsulphonylpropane, 314.
$C_{12}H_{18}O_5S_2$ β-Hydroxy-α-benzylsulphonyl-γ-ethylsulphonylpropane, 314.
$C_{12}H_{19}ON$ 1:6-Dimethyl-$\Delta^{9:10}$-4-octalone oxime, 823.
$C_{12}H_{19}ON_3$ 2-Ketomethyl-$\Delta^{1:9}$-octalin semicarbazones, 58.
2-Methyl-$\Delta^{9:10}$-1-octalone semicarbazone, 822.
$C_{12}H_{19}O_3N$ Ethyl 2-hydroxy-2-cyano-1:3-dimethyl*cyclo*hexane-1-carboxylate, 258.
$C_{12}H_{21}ON_3$ 2-Methyl-1-decalone semicarbazone, 822.
9-Methyl-1-decalone semicarbazone, 817.
cis-9-Methyl-2-decalone semicarbazone, 1143.
$C_{12}H_{21}O_2N$ Base *Z*, and its oxalate, 1820.
$C_{12}H_{21}O_4N$ Ethyl piperidino-1-acetate-4-carboxylate, 1989.
$C_{12}H_{23}ON$ 2-Methyl-6-diethylaminomethyl*cyclo*hexanone, 57.
$C_{12}H_{23}O_3N_3$ Ethyl 8-ketononoate semicarbazone, 723.
9-Ketoundecoic acid semicarbazone, 950.
$C_{12}H_{23}O_6N$ *N*-Acetyl trimethyl α- and β-methylglucosaminides, 1981.
$C_{12}H_{25}O_2N$ *N*-Bromo-11-methylaminoundecoic acid, and its hydrochloride, 716.

12 IV

$C_{12}H_4O_5NBr$ 4-Bromo-3-nitronaphthalic anhydride, 1766.
$C_{12}H_6O_2NBr$ 3-Bromoacenaphthenequinoneoxime, 1762.
3-Bromonaphthalimide, 1765.
$C_{12}H_7O_2N_2Cl$ 2-Chloro-β-carboline-4-carboxylic acid, 472.
$C_{12}H_7O_2Cl_3S_2$ 2:5-Dichlorophenyl 4-chlorobenzenethiolsulphonate, 489.
$C_{12}H_8ON_2Cl_2$ *N*-Nitroso-2:4′-dichlorodiphenylamine, 1956.
$C_{12}H_8O_2NBr$ 3-Bromo-2-nitroacenaphthene, 1766.
$C_{12}H_8O_5N_3Cl$ 4-Chloro-2′:4′-dinitro-2-hydroxydiphenylamine, 41.
5-Chloro-2′:4′-dinitro-2-hydroxydiphenyl ether, 41.
$C_{12}H_8O_5N_3I$ 5-Iodo-2′:4′-dinitro-2-aminodiphenyl ether, 40.
4-Iodo-2′:4′-dinitro-2-hydroxydiphenylamine, 40.
$C_{12}H_9ON_2Cl$ *N*-Nitroso-*p*-chlorodiphenylamine, 1956.
$C_{12}H_9NClBr$ 4-Chloro-4′-bromodiphenylamine, 1956.
$C_{12}H_{11}O_3N_2Cl$ 4-Chloro-5-nitro-6-ethoxy-2-methylquinoline, 426.
$C_{12}H_{12}ONCl$ 4-Chloro-6-ethoxy-2-methylquinoline, 426.
$C_{12}H_{15}O_2N_2I$ *N*-Methyl-3-dimethylaminophthalimide methiodide, 588.
$C_{12}H_{17}O_2ClS_2$ β-Chloro-γ-ethylthio-α-benzylsulphonylpropane, 313.
$C_{12}H_{17}O_3NS$ Thioformylmezcaline, 363.
$C_{12}H_{17}O_4NS$ Mesitylenesulphonylsarcosine, 1696.
N-*m*-Xylene-4-sulphonyl-*N*-ethylglycine, 1696.
$C_{12}H_{17}O_4ClS_2$ β-Chloro-α-benzylsulphonyl-γ-ethylsulphonylpropane, 314.
$C_{12}H_{27}ClPAu$ Chlorotri-*n*-butylphosphinegold, 1832.
$C_{12}H_{27}IPAu$ Iodotri-*n*-butylphosphinegold, 1832.

12 V

$C_{12}H_7O_4NCl_2S$ 4:4′-Dichloro-3-nitrodiphenylsulphone, 244.
$C_{12}H_7O_4N_2ClS$ 5-Chloro-2:4-dinitrodiphenyl sulphide, 248.
$C_{12}H_7O_6N_2ClS$ 5-Chloro-2:4-dinitrodiphenylsulphone, 248.
$C_{12}H_{13}ON_2ClS$ *N*-*o*-Acetamidophenyl-4-methylthiazolium chloride, 962.
$C_{12}H_{14}ON_3Cl_3S$ 3-(2′:4′-Dichloro-6′-methylpyrimidyl-5′-methyl)-5-β-hydroxyethyl-4-methylthiazolium chloride, 495.
3-(2′:4′-Dichloro-6′-methylpyrimidyl-5′-methyl)-4-methyl-5-β-hydroxyethylthiazolium chloride, 1508.
$C_{12}H_{16}ON_4Cl_2S$ 3-(2′-Chloro-4′-amino-6′-methylpyrimidyl-5′-methyl)-4-methyl-5-β-hydroxyethylthiazolium chloride, 1508.
$C_{12}H_{18}O_2N_3ClS$ 3-(4′-Hydroxy-2′-methylpyrimidyl-5′-methyl)-4-methyl-5-β-hydroxyethylthiazolium chloride, hydrochloride of, 1506.
$C_{12}H_{18}ON_4Cl_2S$ Aneurin chloride, 367.

12 VI

$C_{12}H_{14}ON_3Cl_2IS$ 3-(2′:4′-Dichloro-6′-methylpyrimidyl-5′-methyl-4-methyl-5-β-hydroxyethylthiazolium iodide, 1508.

C_{13} Group.

$C_{13}H_{12}$ α-*iso*Propenylnaphthalene, 1790.
$C_{13}H_{18}$ 2-Methyl-2-ethyltetralin, 257.

13 II

$C_{13}H_8O_2$ Dibenzfuran-3-aldehyde, 779.
$C_{13}H_9N$ Phenanthridine, and its salts, 1171.
$C_{13}H_{10}O_3$ Benzylidenephloroglucide, 843.
$C_{13}H_{10}O_7$ 7-Hydroxy-5-methoxy-6-formylcoumarin-7-*O*-acetic acid, 293.
$C_{13}H_{12}O$ 6-Methoxy-1-vinylnaphthalene, 1319.
$C_{13}H_{12}O_3$ 4:8-Dimethoxy-1-naphthaldehyde, 940.
$C_{13}H_{12}O_4$ 1:5-Dimethoxy-2-naphthoic acid, 940.
 4:8-Dimethoxy-1-naphthoic acid, 940.
$C_{13}H_{12}O_6$ 5:6-Dimethoxy-6-methylcoumarin-3-carboxylic acid, 289.
$C_{13}H_{13}N$ 5:6:7:8-Tetrahydrophenanthridine, and its picrate, 1179.
$C_{13}H_{14}O_3$ 5-Acetoxy-6-acetylhydrindene, 478, 561.
 Trimethoxynaphthalenes, 1861.
$C_{13}H_{14}O_4$ 7-Acetoxy-2:2-dimethylchromanone, 1532.
$C_{13}H_{14}N_2$ 9-Methyl-2:3:4:9-tetrahydrophenazine, 1703.
$C_{13}H_{15}O_3$ 5-Methoxy-7-ethoxy-8-methylcoumarin, 290.
$C_{13}H_{16}O$ 2-Methyl-2-ethyl-1-tetralone, 257.
$C_{13}H_{16}O_2$ Xanthone, structure of, 196.
$C_{13}H_{16}O_3$ γ-Benzoyl-ββ-dimethyl-*n*-butyric acid, 1015.
 β-Benzoyl-α-methyl-α-ethylpropionic acid, 257.
$C_{13}H_{16}O_4$ 5:7-Dimethoxy-2:2-dimethylchromanone, 284.
 7-Hydroxy-5-methoxy-6-formyl-2:2-dimethylchroman, 291.
 7-Hydroxy-5-methoxy-8-formyl-2:2-dimethylchroman, 1548.
$C_{13}H_{16}N_2$ Aminomethyltetrahydrocarbazoles, 1129.
$C_{13}H_{17}O_4$ Deoxy*apo*xanthoxyletin ethyl ether, 290.
$C_{13}H_{18}O_2$ β-Benzyl-α-methyl-α-ethylpropionic acid, 257.
 δ-Phenyl-ββ-dimethyl-*n*-valeric acid, 1015.
$C_{13}H_{18}O_3$ 5:7-Dimethoxy-2:2-dimethylchroman, 291.
 Ethyl 2-keto-$\Delta^{1:9}$-octalin-10-carboxylate, 56.
 Ethyl 5-phenoxyvalerate, 725.
 5-Keto-6-carbethoxy-3-methyl-$\Delta^{4:9}$-tetrahydrohydrindene, 59.
$C_{13}H_{18}O_4$ αβ-Dihydroxy-β-cumyl-α-methylpropionic acid, 763.
$C_{13}H_{18}N_2$ Amino-6-methylhexahydrocarbazoles, 1128.
 9-Methyloctahydrophenazine, 1704.
$C_{13}H_{20}O_2$ Methyl δθ-dimethyl-$\Delta^{\alpha\gamma\eta}$-nonatriene-α-carboxylate, 758.
$C_{13}H_{20}O_3$ Ethyl *cis*-2-decalone-3-carboxylate, 824.
$C_{13}H_{20}O_7$ Trimethyl gluco-ascorbic acid acetone, 553.
$C_{13}H_{21}N$ *p*-Amino-*n*-heptylbenzene, and its hydrochloride, 1122.
 n-Heptylaniline, and its hydrochloride, 1122.
$C_{13}H_{22}O_4$ Ethyl 7:9-diketo-2-methyldecoate, 66.
 Ethyl 2-methyl-Δ^1-*n*-hexene-1:6-dicarboxylate, 1977.
$C_{13}H_{24}O_3$ Ethyl 2-methyl-1-γ-hydroxypropyl*cyclo*hexane-2-carboxylate, 1161.

13 III

$C_{13}H_8O_2S_2$ Thianthrencarboxylic acid, 444.
$C_{13}H_8O_3S$ Phenoxthioninecarboxylic acid, and its salts, 446.
$C_{13}H_9O_2N$ Dibenzfuran-3-aldehyde oxime, 779.
$C_{13}H_9NS$ 4-Diphenylyl *iso*thiocyanate, 1700.
$C_{13}H_{10}ON_4$ Benzylideneaminoacetimidosuccinonitrile, 1436.
$C_{13}H_{10}O_3N_2$ Methyl 2-keto-2:3-dihydro-β-carboline-4-carboxylate, 470.
$C_{13}H_{10}N_2O_2$ Methyl norharmancarboxylate, 472.
$C_{13}H_{10}N_2S$ *N*-Thiocarbimidodiphenylamine, 1362.
$C_{13}H_{11}O_3Br$ Methyl 8-bromo-7-methoxy-1-naphthoate, 537.
$C_{13}H_{11}O_5N_3$ 2′:4′-Dinitro-2-amino-5-methyldiphenyl ether, 40.
 2′:4′-Dinitro-2-hydroxy-4-methyldiphenylamine, and its salts, 40.
$C_{13}H_{11}O_6N_3$ 2′:4′-Dinitro-2-amino-5-methoxydiphenyl ether, 39.
 2′:4′-Dinitro-2-hydroxy-4-methoxydiphenylamine, 39.
$C_{13}H_{12}O_2N_2$ 1-Nitro-5:6:7:8-tetrahydrophenanthridine, and its picrate, 1172.
$C_{13}H_{12}NCl$ 3-Chloro-5:6:7:8-tetrahydrophenanthridine, and its picrate, 1172.
$C_{13}H_{12}NBr$ 3-Bromo-5:6:7:8-tetrahydrophenanthridine, and its picrate, 1172.
$C_{13}H_{12}N_3Br$ 1-*p*-Bromophenyl-3-phenyl-3-methyltriazen, 324.
$C_{13}H_{13}O_3I$ 8-Iodo-1:2:7-trimethoxynaphthalene, 1862.
$C_{13}H_{13}O_5N$ Nitrotrimethoxynaphthalenes, 1862.
$C_{13}H_{14}O_2N_2$ 8-Nitro-6-methyltetrahydrocarbazole, 1128.
$C_{13}H_{15}O_3N$ 8-Amino-1:2:7-trimethoxynaphthalene, 1862.
$C_{13}H_{15}O_4N$ Methyl 1-keto-1:2-dihydro*iso*quinoline-3-orthoformate, and its potassium salt, 474.
$C_{13}H_{15}O_6N_3$ α-Ketopimelic acid *p*-nitrophenylhydrazone, 813.
$C_{13}H_{15}N_2I$ 1:2:3:4-Tetrahydrophenazine methiodide, 1703.
$C_{13}H_{16}ON_2$ 6-Hydroxy-3-phenyl-5-methyl-5-ethyltetrahydropyridazine, 257.

$C_{13}H_{16}O_3N_2$ ω-Aldehydo-γ-keto-α-phenyl-Δ^{α}-hexenedione, 302.
Methyl-Δ^1-*cyclo*hexene nitrosoketoanilide, 375.
Donaxarine, 1928.
$C_{13}H_{16}O_4N_2$ α-Ketopimelic acid phenylhydrazone, 812.
$C_{13}H_{16}O_6N_4$ αγ-Methylenedioxy-β-acetyl-β-methylpropane 2:4-dinitrophenylhydrazone, 844.
$C_{13}H_{17}ON$ Methyl-Δ^1-*cyclo*hexeneketoanilide, 375.
$C_{13}H_{17}O_2N_3$ Methyl-Δ^1-*cyclo*hexenenitrosonitrolanilide, 375.
$C_{13}H_{17}O_4N$ Ethyl 4-carbethoxyphenylaminoacetate, 454.
Ethyl 2-pyridylsuccinate, and its picronolate, 968.
$C_{13}H_{17}O_4N_3$ Methyl α-methyl-lævulate *p*-nitrophenylhydrazone, 1346.
$C_{13}H_{18}ON_2$ Methyl-Δ^1-*cyclo*hexenenitrolanilide, 375.
$C_{13}H_{19}ON$ *p*-Acetamido-*n*-amylbenzene, 1120.
$C_{13}H_{19}ON_3$ Cuminyl methyl ketone semicarbazone, 763.
$C_{13}H_{19}O_2N$ Ethyl hexahydroquinaldine-3-carboxylate, and its picronolate, 1529.
$C_{13}H_{19}O_3N$ Ethyl 2-γ-cyanopropyl*cyclo*hexanone-2-carboxylate, 821.
$C_{13}H_{19}O_4N$ Ethyl cyanonorcaryophyllenate, 1341.
$C_{13}H_{19}O_{11}N$ 2:3:6-Triacetyl β-methylglucoside 4-nitrate, 1717.
$C_{13}H_{19}N_2I$ Octahydrophenazine methiodide, 1704.
Gramine ethiodide, 1929.

13 III

$C_{13}H_{20}O_5N_2$ Fructosemethylphenylhydrazone, 1324.
$C_{13}H_{20}O_{13}N_2$ 6-Acetyl 4-α-acetoxyethyl β-methylglucoside, 1715.
$C_{13}H_{21}ON_3$ 1:6-Dimethyl-$\Delta^{9:10}$-4-octalone semicarbazone, 823.
$C_{13}H_{21}O_2N$ 4:5-Dimethoxy-2-ethylbenzyldimethylamine, and its picrate, 429, 432.
Tigloidine, and its salts, 1820.
$C_{13}H_{21}O_5N$ Ethyl α-carbethoxy-γ-cyano-β-ethoxymethylbutyrate, 1062.
$C_{13}H_{22}O_4Br_2$ *iso*Amyl dibromomalonate, 1811.
$C_{13}H_{23}O_2N$ Dihydrotigloidine, 1822.
$C_{13}H_{23}O_2I$ Ethyl 2-methyl-1-(γ-iodopropyl)*cyclo*hexane-2-carboxylate, 817.
$C_{13}H_{23}O_3N$ Valeroidine, and its salts, 1820.
$C_{13}H_{23}O_3N_3$ γ-(2-Keto-4-methyl*cyclo*hexyl)valeric acid semicarbazone, 823.
$C_{13}H_{23}O_4N$ Ethyl piperidyl-1:2-diacetate, 1520.
$C_{13}H_{23}O_4Br$ Amyl bromomalonates, 1811.

13 IV

$C_{13}H_6ONBr_3$ 1:3:7-Tribromoacridone, 1958.
$C_{13}H_7ONCl_4$ 2:4:4′-Trichlorodiphenylcarbamyl chloride, 1956.
$C_{13}H_8O_2NBr_3$ 4:6:4′-Tribromodiphenylamine-2-carboxylic acid, 1958.
$C_{13}H_8O_3N_3I_3$ 2:4:6-Tri-iodo-3-methoxylbenzaldehyde *p*-nitrophenylhydrazone, 77.
$C_{13}H_8O_5N_4I_2$ Di-iodonitro-3-hydroxybenzaldehyde *p*-nitrophenylhydrazones, 78.
$C_{13}H_8O_7N_5I$ 4-Iodo-2:6-dinitro-3-hydroxybenzaldehyde *p*-nitrophenylhydrazone, 78.
$C_{13}H_9ONS$ Thianthrencarboxyamide, 444.
$C_{13}H_9O_2N_2Cl$ Methyl 2-chloro-β-carboline-4-carboxylate, 472.
$C_{13}H_9O_2N_3S$ 5-Nitro-1-anilinobenzthiazole, and its picrate, 1516.
$C_{13}H_9N_2ClS$ 5-Chloro-1-anilinobenzthiazole, and its picrate, 1516.
$C_{13}H_9N_2BrS$ 5-Bromo-1-anilinobenzthiazole, and its picrate, 1515.
$C_{13}H_{10}O_3NCl$ Chloronitromethyldiphenyl ethers, 1021.
$C_{13}H_{10}O_3N_2S$ *N*-Methylphenazoniumsulphonic acid betaine, 1710.
$C_{13}H_{10}O_3N_3I$ 6-Iodo-3-hydroxybenzaldehyde *p*-nitrophenylhydrazone, 77.
$C_{13}H_{10}O_4NBr$ α-Bromo-δ-phthalimido-γ-valerolactone, 1168.
$C_{13}H_{11}O_3N_2S$ *N*-Methylphenazylsulphonic acid betaine, 1710.
$C_{13}H_{11}O_6N_2S_2$ *N*-Methylphenazyldisulphonic acid betaine, sodium hydrogen salt, 1710.
$C_{13}H_{12}O_2NBr$ 3-Bromo-2-naphthylurethane, 1529.
$C_{13}H_{12}O_3N_2S$ *N*-Methyldihydrophenazinesulphonic acid, sodium salt, 1709.
$C_{13}H_{13}O_2N_2Cl$ 8-Chloro-5-nitro-3-methyltetrahydrocarbazole, 1129.
$C_{13}H_{13}O_2N_2Br$ 8-Bromo-5-nitro-6-methyltetrahydrocarbazole, 1128.
$C_{13}H_{13}O_5NS$ *N*-2-Methoxynaphthalene-1-sulphonylglycine, 1696.

13 V

$C_{13}H_9O_4N_2ClS$ 5-Chloro-2:4-dinitro-4′-methyldiphenyl sulphide, 247.
$C_{13}H_9O_6N_2ClS$ 5-Chloro-2:4-dinitro-4′-methyldiphenylsulphone, 248.
$C_{13}H_{10}O_2NClS$ Chloronitro-4′-methyldiphenyl sulphides, 245.
$C_{13}H_{10}O_3NClS$ Chloronitrohydroxymethyldiphenyl sulphides, 1019.
$C_{13}H_{10}O_4NClS$ Chloronitro-4′-methyldiphenylsulphones, 245.
$C_{13}H_{11}O_2ClS$ 2-Chloro-4′-methyldiphenylsulphone, 245.
$C_{13}H_{12}O_2NClS$ Chloroamino-4′-methyldiphenylsulphones, 245.
$C_{13}H_{19}ON_4ClS$ 2-Methylaneurin chloride, salts of, 1507.
$C_{13}H_{22}O_2NSP$ Triethylphosphine-*p*-toluenesulphonylimine, 535.
$C_{13}H_{24}O_2N_4S$ *p*-Toluenesulphonyl-*NN′*-bis-(β-aminoethyl)ethylenediamine, trihydrochloride of, 1471.

C_{14} Group.

$C_{14}H_{12}$ *as*-Diphenylethylene, polymerisation of, 1790.

14 II

$C_{14}H_{8}O_{6}$ Tetrahydroxyanthraquinones, 254.
$C_{14}H_{9}N_{3}$ 2′:4-Anhydro-2′-amino-3-phenylphthalaz-4-one, 96.
$C_{14}H_{10}O_{6}$ Hydroxyjuglone diacetate, 1600.
$C_{14}H_{10}N_{3}$ *N*-Methylphenazyl-2-nitrile, 1709.
$C_{14}H_{11}N$ 7-Methylphenanthridine, and its picrate, 1172.
$C_{14}H_{11}N_{3}$ *N*-Methyldihydrophenazine-2-nitrile, 1709.
$C_{14}H_{12}O_{2}$ *l*-Benzoin, rotation of, in various solvents, 139.
$C_{14}H_{12}O_{3}$ Xanthyletin, constitution of, 1542.
$C_{14}H_{12}Cl_{2}$ 2:2′-Dichloro-4:4′-dimethyldiphenyl, 269.
$C_{14}H_{12}I_{2}$ 2:2′-Di-iodo-4:4′-dimethyldiphenyl, 270.
$C_{14}H_{12}F_{2}$ 2:2′-Difluoro-4:4′-dimethyldiphenyl, 268.
$C_{14}H_{12}S_{2}$ Diphenylthioethylene, 769.
$C_{14}H_{13}N_{2}$ *N*-Ethylphenazyl, 1710.
$C_{14}H_{13}Cl$ 2-Chloro-4:4′-dimethyldiphenyl, 268.
$C_{14}H_{13}Br$ 2-Bromo-4:4′-dimethyldiphenyl, 269.
$C_{14}H_{13}F$ 2-Fluoro-4:4′-dimethyldiphenyl, 268.
$C_{14}H_{13}I$ 2-Iodo-4:4′-dimethyldiphenyl, 270.
$C_{14}H_{14}O$ 2-Hydroxy-4:4′-dimethyldiphenyl, 271.
$C_{14}H_{14}O_{2}$ 1-Keto-7-hydroxyhexahydrophenanthrene, 63.
5-Methoxy-2-allyl-1-naphthol, 939.
5-Methoxy-1-methyl-1:2-dihydro-*a*-naphthafuran, 939.
5-Methoxy-1-naphthyl allyl ether, 939.
$C_{14}H_{14}O_{3}$ Dihydroxanthyletin, 1544.
γ-5-Hydroxy-1-naphthylbutyric acid, 1621.
β-(6-Methoxy-1-naphthyl)propionic acid, 70.
$C_{14}H_{14}O_{4}$ Methyl 1:5-dimethoxy-2-naphthoate, 940.
Methyl 4:8-dimethoxy-1-naphthoate, 940.
$C_{14}H_{14}O_{6}$ 5-Methoxy-7-ethoxy-8-methylcoumarin-3-carboxylic acid, 290.
$C_{14}H_{14}N_{2}$ *N*-Ethyldihydrophenazine, 1710.
$C_{14}H_{15}N$ Methyltetrahydrophenanthridines, and their picrates, 1171.
$C_{14}H_{15}N_{3}$ 3-Phenyl-1-*m*-tolyl-3-methyltriazen, 324.
$C_{14}H_{16}O_{3}$ *β*-(6-Methoxy-3:4-dihydro-1-naphthyl) propionic acid, 70.
Tetrahydroxanthyletin, 1545.
$C_{14}H_{16}O_{4}$ *cis-p*-Phenoxymethyl-*a*-ethylglutaric anhydride, 1060.
$C_{14}H_{16}O_{6}$ Ethyl veratroylpyruvate, 1648.
$C_{14}H_{18}O$ Anisoxide, 513.
$C_{14}H_{18}O_{2}$ 4-Phenyl*cyclo*hexylacetic acid, 1560.
$C_{14}H_{18}O_{3}$ *γ*-Benzoyl-*β*-methyl-*β*-ethyl-*n*-butyric acid, 1015.
4-Hydroxy-7-*m*-methoxyphenylheptolactone, 69.
β-(6-Methoxy-1:2:3:4-tetrahydro-1-naphthyl)propionic acid, 70.
$C_{14}H_{18}O_{4}$ 2:6-Dimethoxy-4-ethoxy-3-methylcinnamic acid, 290.
5:7-Dimethoxy-6-formyl-2:2-dimethylchroman, 291.
5:7-Dimethoxy-8-formyl-2:2-dimethylchroman, 1548.
4-Keto-7-*m*-methoxyphenylheptoic acid, 69.
$C_{14}H_{18}O_{5}$ 5:7-Dimethoxy-2:2-dimethylchroman-6-carboxylic acid, 292.
β-Phenoxymethyl-*a*-ethylglutaric acids, 1060.
$C_{14}H_{20}O$ Dihydroanisoxide, 515.
2-Keto-$\Delta^{1:13}$-dodecahydroanthracene, 59.
$C_{14}H_{20}O_{2}$ *δ*-Phenyl-*β*-methyl-*β*-ethyl-*n*-valeric acid, 1015.
$C_{14}H_{20}O_{3}$ 8-Phenoxyoctoic acid, 725.
$C_{14}H_{22}O_{3}$ Ethyl 3-methyl-2-decalone-3-carboxylates, 825.
$C_{14}H_{22}O_{5}$ Ethyl 2-carbethoxy*cyclo*hexanone-2-*β*-propionate, 944.
Ethyl 6-carbethoxy*cyclo*hexanone-2-*β*-propionate, 945.
$C_{14}H_{23}N$ *n*-Octylaniline, 1122.
$C_{14}H_{24}O_{5}$ Ethyl *a*-acetylsuberate, 722.
$C_{14}H_{24}O_{7}$ Methyl 2-methylgluconate diacetone, 796.
$C_{14}H_{26}O$ Perhydroanisoxide, 514.
$C_{14}H_{26}O_{2}$ Ethyl Δ^{1}-dihydrocitronellylideneacetate, 1590.
$C_{14}H_{26}O_{3}$ 12-Acetyl-lauric acid, 1001.
Ethyl 2-methyl-1-*γ*-methoxypropyl*cyclo*hexane-2-carboxylate, 1160.
$C_{14}H_{26}O_{4}$ 4:13-Diketotetradecoic acid, 714.
Ethyl 2-methyl-1-*γ*-methoxypropyl*cyclo*hexan-1-ol-2-carboxylate, 65.
$C_{14}H_{26}O_{5}$ 5-Carbethoxyamyl 6-hydroxyhexoate, 373.
$C_{14}H_{28}O_{3}$ Hydroxy*iso*myristic acid, 713.

14 III

$C_{14}H_{8}N_{3}Cl$ 2′:4-Anhydro-4′-chloro-2′-amino-3-phenylphthalaz-4-one, 97.
$C_{14}H_{9}O_{4}N_{3}$ 3-Nitro-*N*-anilinophthalimide, 31.
$C_{14}H_{10}ON_{2}$ 3-Hydroxy-2-phenylquinoxaline, 549.
$C_{14}H_{10}Cl_{2}S_{2}$ *s*-Dichlorodiphenylthioethylene, 770.
$C_{14}H_{11}OBr$ *p*-Bromodeoxybenzoin, 847.
$C_{14}H_{11}O_{2}N_{3}$ 3-Amino-*N*-anilinophthalimide, 1844.
Dibenzfuran-3-aldehyde semicarbazone, 779.

$C_{14}H_{11}O_2Br$ 2-Bromo-*p*-tolyl benzoate, 264.
$C_{14}H_{11}O_3N_3$ Phenylglyoxal *p*-nitrophenylhydrazone, 370.
$C_{14}H_{11}O_4Br$ Methyl 3-bromonaphthalate, 1765.
$C_{14}H_{12}ON_2$ Keto-*N*-ethylphenazines, 1710.
$C_{14}H_{12}O_2N_2$ Methyl 1-methyl-β-carboline-4-carboxylate, 473.
$C_{14}H_{12}O_3N_2$ Ethyl 2-keto-2:3-dihydro-β-carboline-4-carboxylate, 470.
Methyl 2-keto-3-methyl-2:3-dihydro-β-carboline-4-carboxylate, 471.
$C_{14}H_{12}O_5N_4$ Anisaldehyde 2:4-dinitrophenylhydrazone, 369.
$C_{14}H_{12}O_6N_2$ 3:3′-Dinitro-4:4′-dimethoxydiphenyl, 38.
$C_{14}H_{12}O_6S$ 2-*O*-*p*-Toluenesulphonylphloroglucinaldehyde, 455.
$C_{14}H_{13}O_3N$ 2-Nitro-4-benzyloxytoluene, 1726.
$C_{14}H_{14}O_5N_4$ 3:6-Diacetamido-*N*-acetamidophthalimide, 590.
$C_{14}H_{14}O_5S_2$ (Benzenesulphonyl) (methylsulphonyl)benzoylmethane, 1512.
$C_{14}H_{14}O_7N_4$ Ethyl 2-(2′:4′-dinitrobenzeneazo)*cyclo*pentanone-2-carboxylate, 811.
$C_{14}H_{14}NF$ 2-Fluoro-2′-amino-4:4′-dimethyldiphenyl, 268.
$C_{14}H_{15}ON$ 3-Methoxy-5:6:7:8-tetrahydrophenanthridine, and its picrate, 1172.
$C_{14}H_{15}ON_3$ 1-Methoxyphenyl-3-phenyl-3-methyltriazens, 324.
$C_{14}H_{15}O_3Br$ β-(6-Methoxy-3:4-dihydro-1-naphthyl)propionobromolactone, 70.
$C_{14}H_{16}O_2N_2$ 3:3′-Diamino-4:4′-dimethoxydiphenyl, and its hydrochloride, 38.
$C_{14}H_{16}O_8N_4$ Ethyl hydrogen α-ketoadipate 2:4-dinitrophenylhydrazone, 811.
$C_{14}H_{16}N_2S_2$ 3:3′-Diamino-4:4′-dimethylthioldiphenyl, and its salts, 38.
$C_{14}H_{17}O_2N$ Ethyl *cyclo*pentanone-2-carboxylate anil, 810.
$C_{14}H_{17}O_3N$ β-Phenoxymethyl-α-ethylglutarimide, 1060.
$C_{14}H_{17}O_4N$ Methyl 1-keto-2-methyl-1:2-dihydro*iso*quinoline-3-orthoformate, 475.
$C_{14}H_{17}O_5N$ 4-Carbethoxymethylamino-ω-acetoxyacetophenone, 454.
$C_{14}H_{18}O_4S_2$ βδ-Bis(ethylsulphonyl)-α-phenylbutadiene, 318.
$C_{14}H_{19}ON$ Δ^{6}-*n*-Heptenoic acid *p*-toluidide, 1973.
4-Phenyl*cyclo*hexylacetamide, 1560.
$C_{14}H_{19}O_3N_3$ 2-Hydroxymethyl-4-methyl*cyclo*hexanone *p*-nitrophenylhydrazone, 1170.
$C_{14}H_{20}O_4S_2$ α-Benzylsulphonyl-γ-ethylsulphonyldimethylpropylene, 320.
$C_{14}H_{20}O_7S$ 3-*p*-Toluenesulphonyl-5-methyl methylxylofuranosides, 1601.
$C_{14}H_{21}ON$ *p*-Acetamido-*n*-hexylbenzene, 1121.
$C_{14}H_{21}O_3N$ 9-2′-Pyrroylnonoic acid, 717.
$C_{14}H_{22}O_6S_3$ α-Benzylsulphonylbis(ethylsulphonyl)propane, 312.
$C_{14}H_{23}O_5N_3$ 3-Carbethoxy-1-methyl-4-*iso*propenyl*cyclo*hexan-2-one-1-β-propionic acid semicarbazone, 1579.
$C_{14}H_{23}O_4N$ Ethyl α-cyano-γ-acetyl-β-ethoxymethyl-α-ethylbutyrate, 1063.
$C_{14}H_{25}O_2N$ Carpaine, constitution of, 711.
$C_{14}H_{25}O_3Br$ 13-Bromo-4-ketotetradecoic acid, 714.
$C_{14}H_{25}O_4N$ Ethyl piperidyl-2-acetate-1-β-propionate, 1521.
$C_{14}H_{27}O_3N$ Deoxycarpamic acid, 713.

14 IV

$C_{14}H_8O_4N_3Cl$ *N*-4′-Chloro-2′-nitrophenylaminophthalimide, 103.
$C_{14}H_9O_5NS$ 3-Nitro-8-methylphenoxthionine-1-carboxylic acid, 445.
$C_{14}H_{10}ONCl$ 4-Chloro-9-acetylcarbazole, 1128.
$C_{14}H_{10}ON_3Cl$ 4′-Chloro-2′-amino-3-phenylphthalaz-4-one, 97.
$C_{14}H_{10}O_2NCl$ 3-Chloro-7-methoxyacridone, 1958.
$C_{14}H_{10}O_5N_3Cl$ *o*-Carboxybenzo-4′-chloro-2′-nitrophenylhydrazide, 103.
$C_{14}H_{10}O_5N_4I_2$ 2:4-Di-iodo-6-nitro-3-methoxybenzaldehyde *p*-nitrophenylhydrazone, 78.
$C_{14}H_{10}O_6NBr$ α-Bromo-δ-phthalimido-α-carboxy-γ-valerolactone, 1168.
$C_{14}H_{11}ONS_2$ 2-Acetamidothianthren, 1592.
$C_{14}H_{11}O_2N_3S$ 5-Nitro-1-phenylmethylaminobenzthiazole, and its picrate, 1516.
$C_{14}H_{11}N_2ClS$ 5-Chloro-1-phenylimino-2-methyl-1:2-dihydrobenzthiazole, and its picrate, 1516.
5-Chloro-1-phenylmethylaminobenzthiazole, and its picrate, 1516.
$C_{14}H_{11}N_2BrS$ 5-Bromo-1-phenylimino-2-methyl-1:2-dihydrobenzthiazole, and its picrate, 1515.
5-Bromo-1-phenylmethylaminobenzthiazole, and its picrate, 1516.
$C_{14}H_{12}ONBr$ Benzoyl-2-bromo-*p*-toluidine, 264.
$C_{14}H_{12}O_2NF$ 2-Fluoro-2′-nitro-4:4′-dimethyldiphenyl, 268.
$C_{14}H_{12}O_2N_2Cu$ Cupric salicylaldimine, 2002.
$C_{14}H_{14}O_2N_4Cu$ Cupric salicylidenehydrazone, 2002.
$C_{14}H_{14}O_2N_4Ni$ Nickel salicylidenehydrazone, 2003.
$C_{14}H_{12}O_2Cl_2S$ 5-Chloro-*o*-cresol 3-sulphide, 1021.
$C_{14}H_{12}O_3NCl$ Chloronitrodimethyldiphenyl ethers, 1020.
$C_{14}H_{12}O_4Cl_2S_2$ 2:5-Dichlorophenyl 4-methoxy-*m*-toluenethiolsulphonate, 489.
$C_{14}H_{12}O_4N_2S_2$ 3:3′-Dinitro-4:4′-dimethylthioldiphenyl, 38.
$C_{14}H_{12}O_5NClS$ 5-Chloro-2-*o*-nitrophenoxy-3:6-dimethylbenzenesulphinic acid, 1020.
$C_{14}H_{13}O_2NS$ 2-Nitrodi-*p*-tolyl sulphide, 246.
$C_{14}H_{13}O_3NS$ 2′-Nitro-2-hydroxy-4:5-dimethyldiphenyl sulphide, 1019.
$C_{14}H_{13}O_3ClS$ Chloromethoxy-4′-methyldiphenylsulphones, 245.
$C_{14}H_{13}O_4NS$ 2-Nitrodi-*p*-tolylsulphone, 246.
$C_{14}H_{14}ONCl$ Chloro-9-acetyltetrahydrocarbazoles, 1127.
$C_{14}H_{15}O_5NS$ *N*-2-Methoxynaphthalene-1-sulphonylsarcosine, 1696.
$C_{14}H_{24}O_2NCl$ 4:5-Dimethoxy-2-ethylbenzyltrimethylammonium chloride, 429.
$C_{14}H_{24}O_2NI$ 4:5-Dimethoxy-2-ethylbenzyltrimethylammonium iodide, 429

14 V

$C_{14}H_{12}O_3NClS$ Chloronitrohydroxydimethyldiphenyl sulphides, 1019.
$C_{14}H_{14}O_3NClS$ ω-Chloro-4-*p*-toluenesulphonamidoacetophenone, 454.

C_{15} Group.

$C_{15}H_{10}O_2$ 1-Methylphenanthra-3:4-quinone, 512.
2-Methylphenanthrene-1:4-quinone, 262.
$C_{15}H_{10}O_3$ β-Dibenzfuran-3-acrylic acid, 779.
$C_{15}H_{10}O_5$ 1:3:4-Trihydroxy-2-methylanthraquinone, 88.
$C_{15}H_{10}O_7$ 3:5:6:7:4′-Pentahydroxyflavone, 48.
$C_{15}H_{11}O_5$ ψ-Baptigenin, 806.
$C_{15}H_{11}N_3$ 2′:4-Anhydro-2′-amino-3-phenyl-1-methylphthalaz-4-one, 98.
2:2′:2″-Tripyridyl, complex salts of, 1649.
$C_{15}H_{12}O$ 3-Hydroxy-1-methylphenanthrene, 512.
4-Hydroxy-1-methylphenanthrene, 266.
8-Hydroxy-1-methylphenanthrene, 1621.
$C_{15}H_{12}O_3$ Dihydroxyphenyl styryl ketones, 423, 1738.
7-Hydroxyflavanone, 1738.
$C_{15}H_{12}O_4$ 2:4:4′-Trihydroxychalkone, 423.
$C_{15}H_{12}O_5$ Tetrahydroxychalkones, 424.
$C_{15}H_{12}O_6$ Droserone diacetate, 1599.
$C_{15}H_{13}N$ Dimethylphenanthridines, and their picrates, 1171.
$C_{15}H_{14}O$ αβ-Diphenylpropaldehyde, 548.
$C_{15}H_{14}O_2$ *l*-Benzoin methyl ether, rotation of, in various solvents, 139.
1-Keto-8-methoxytetrahydrophenanthrene, 1621.
Phenylacetylphenylcarbinol, 548.
$C_{15}H_{14}O_4$ β-5-Methoxy-1-naphthoylpropionic acid, 1621.
*allo*Xanthoxyletin, structure of, 1545.
$C_{15}H_{14}O_5$ 1:2-Diacetoxy-7-methoxynaphthalene, 1861.
Dihydroxanthyletin-3-carboxylic acid, 1544.
β-(4-Hydroxy-8-methoxy-1-naphthoyl)propionic acid, 938.
$C_{15}H_{14}O_7$ Ethyl 7-hydroxy-5-methoxy-6-formylcoumarin-7-*O*-acetate, 293.
$C_{15}H_{16}O$ 3-Keto-1-methylhexahydrophenanthrene, 1587.
$C_{15}H_{16}O_2$ 1:5-Dimethoxy-2-allylnaphthalene, 939.
$C_{15}H_{16}O_4$ Dihydro*allo*xanthoxyletin, 1548.
7-Hydroxy-8-*iso*valeryl-4-methylcoumarin, 278.
$C_{15}H_{16}O_5$ Deacetyldecarbousnic acid, 900.
3:6-Diacetoxy-2-*iso*propylbenzofuran, 1533.
$C_{15}H_{17}N$ Dimethyltetrahydrophenanthridines, and their picrates, 1171.
1:9-Trimethylene-1:2:3:4-tetrahydrocarbazole, 945.
$C_{15}H_{18}O_3$ Ethyl γ-phenylpropylideneacetoacetate, 1588.
γ-6-Methoxy-3:4-dihydro-1-naphthylbutyric acid, 63.
1-Phenacyl*cyclo*pentane-1-acetic acid, 1015.
$C_{15}H_{18}O_4$ Tetrahydroxanthoxyletin, 292.
$C_{15}H_{18}O_5$ 5:7-Diacetoxy-2:2-dimethylchroman, 283.
$C_{15}H_{19}N$ 1:9-Trimethylenehexahydrocarbazole, 945.
$C_{15}H_{20}O_2$ 1-β-Phenylethyl*cyclo*pentane-1-acetic acid, 1015.
$C_{15}H_{20}O_3$ Ethyl αβ-epoxy-β-cumyl-α-methylpropionate, 762.
$C_{15}H_{20}O_4$ Ethyl γ-phenoxypropylacetoacetate, 724.
$C_{15}H_{20}O_5$ Methyl 2:6-dimethoxy-4-ethoxy-3-methylcinnamate, 290.
$C_{15}H_{20}O_6$ 5-Benzoyl 2:3-dimethyl γ-methylxyloside, 1603.
$C_{15}H_{22}O$ Cyperones, 1576.
1:10-Dimethyl-7-*iso*propenyl-$\Delta^{1(9)}$-octal-2-one, 1578, 1580.
$C_{15}H_{24}O_2$ 1-Methyl-1-γ-ketopentyl-4-*iso*propenyl*cyclo*hexan-2-one, 1578.
$C_{15}H_{24}O_3$ Ethyl 1-methyl-4-*iso*propenyl*cyclo*hexan-2-one-1-β-propionate, 1579.
$C_{15}H_{24}O_4$ *cyclo*Hexyl malonate, 1811.
$C_{15}H_{24}O_7$ Gluconic acid triacetone, 796.
$C_{15}H_{26}O$ 1:10-Dimethyl-7-*iso*propenyldecal-2-ol, 1580.
$C_{15}H_{26}O_3$ Ethyl 2-methyl-1-(γ-ethoxypropyl)-Δ^{6}-*cyclo*hexene-2-carboxylate, 815.
$C_{15}H_{26}O_7$ Ethyl α-carbethoxy-β-ethoxymethylglutarate, 1062.
$C_{15}H_{28}O_3$ Ethyl 2-methyl-1-(γ-ethoxypropyl)*cyclo*hexane-2-carboxylate, 815.
$C_{15}H_{28}O_4$ Ethyl 1-hydroxy-2-methyl-1-(γ-ethoxypropyl)*cyclo*hexane-2-carboxylate, 815.

15 III

$C_{15}H_{10}O_2N_2$ *N*-Benzylideneaminophthalimide, 21.
$C_{15}H_{10}O_3N_2$ 3-Benzamidephthalimide, 29.
$C_{15}H_{10}N_3Cl$ 2′:4-Anhydro-4′-chloro-2′-amino-3-phenyl-1-methylphthalaz-4-one, 98.
$C_{15}H_{11}O_3N_3$ 5-Benzamidophthalaz-1:4-dione, 30.
2-(2′-Nitrophenylamino)-3-methylene*iso*indolinone, 102.
$C_{15}H_{11}O_4N_3$ *N*-2′-Nitro-4′-methylphenylaminophthalimide, 103.
$C_{15}H_{12}O_5N_4$ *p*-Methoxyphenylglyoxal 2:4-dinitrophenylhydrazone, 370.
$C_{15}H_{13}ON$ Benzyloxyindoles, 1727.

$C_{15}H_{13}ON_3$ 2-(2′-Aminophenylamino)-3-methylene*iso*indolinone, 102.
2′-Amino-3-phenyl-1-methylphthalaz-4-one, 97.
$C_{15}H_{13}O_4N_3$ *p*-Methoxyphenylglyoxal *p*-nitrophenylhydrazone, 370.
$C_{15}H_{13}O_5N_3$ *o*-Carboxybenzo-2′-nitro-4′-methylphenylhydrazide, 103.
$C_{15}H_{13}O_6N_3$ 2′:4′-Dinitro-2-acetamido-5-methyldiphenyl ether, 40.
$C_{15}H_{14}O_3N_2$ Methyl 2-keto-1:3-dimethyl-2:3-dihydro-*β*-carboline-4-carboxylate, 471.
$C_{15}H_{14}O_7N_4$ 2:4-Dihydroxy-6-ethoxybenzaldehyde 2:4-dinitrophenylhydrazone, 280.
$C_{15}H_{14}N_2S$ 1-Phenylimino-2:5-dimethyl-1:2-dihydrobenzthiazole, and its picrate, 1514.
1-Phenylmethylamino-5-methylbenzthiazole, and its picrate, 1514.
$C_{15}H_{14}N_3I$ 2-2′-Pyridylaminoquinoline methiodide, 909.
$C_{15}H_{15}ON$ Tetrahydrocarbazole-1-*β*-propionic acid lactam, 944.
$C_{15}H_{15}O_2N$ 2-Methoxy-*m*-toluanilide, 261.
$C_{15}H_{15}O_3N$ 2′-Nitro-2:4:5-trimethyldiphenyl ether, 1020.
$C_{15}H_{16}O_3S$ Phenyl-2-hydroxy-3:5-dimethylbenzylsulphone, 1351.
$C_{15}H_{16}O_4N_2$ Methyl 2-keto-2:3-dihydro-*β*-carboline-4-orthoformate, 470.
$C_{15}H_{17}O_2N$ 1:4-Dimethoxy-5:6:7:8-tetrahydrophenanthridine, and its picrate, 1172.
Tetrahydrocarbazolenine-11-*β*-propionic acid, 944.
$C_{15}H_{17}O_5N$ *α*-Cyano-*β*-phenoxymethyl-*α*-ethylglutaric acid, 1060.
$C_{15}H_{17}O_5N_3$ Ethyl 2-*p*-nitrobenzeneazo*cyclo*hexanone-2-carboxylate, 813.
$C_{15}H_{18}O_4N_4$ *d*-4-*iso*Propyl-Δ^2-*cyclo*hexen-1-one 2:4-dinitrophenylhydrazone, 1449.
$C_{15}H_{19}O_2N$ *α*-Cyano-*ζχ*-dimethyl-$\Delta^{\alpha\gamma\epsilon}$-undecatetraene-*α*-carboxylic acid, 760.
$C_{15}H_{19}O_2N_3$ *d*-4-*iso*Propyl-Δ^2-*cyclo*hexen-1-one *p*-nitrophenylhydrazone, 1449.
$C_{15}H_{19}O_3N$ Homopilopic acid *p*-toluidides, 1060.
$C_{15}H_{19}O_6N_3$ Ethyl hydrogen *α*-ketopimelate *p*-nitrophenylhydrazone, 813.
$C_{15}H_{20}O_4N_2$ Ethyl hydrogen *α*-ketopimelate phenylhydrazone, 812.
$C_{15}H_{20}O_6N_4$ 8-Ketononoic acid 2:4-dinitrophenylhydrazone, 722.
$C_{15}H_{20}O_7S$ 3-*p*-Toluenesulphonyl 1:2-acetone xylose, 1601.
$C_{15}H_{21}ON_3$ 3-Methyl-7-*iso*propyl-1:2:3:4-tetral-1-one semicarbazone, 763.
$C_{15}H_{21}O_2N_3$ *γ*-Benzoyl-*β*-methyl-*β*-ethyl-*n*-butyric acid semicarbazone, 1015.
$C_{15}H_{21}O_4N_3$ 5:7-Dimethoxy-8-formyl-2:2-dimethylchroman semicarbazone, 291.
4-Keto-7-*m*-methoxyphenylheptoic acid semicarbazone, 69.
$C_{15}H_{22}O_7S$ 3-*p*-Toluenesulphonyl 2:5-dimethyl methylxylofuranosides, 1602.
$C_{15}H_{23}ON$ *p*-Acetamido-*n*-heptylbenzene, 1122.
1:10-Dimethyl-7-*iso*propenyl-$\Delta^{1(9)}$-octal-2-one oxime, 1578, 1580.
$C_{15}H_{23}ON_3$ *α*-Aldehydo-*ζχ*-dimethyl-$\Delta^{\alpha\gamma\epsilon}$-undecatetraene semicarbazone, 759.
$C_{15}H_{23}O_4Br$ *cyclo*Hexyl bromomalonate, 1811.
$C_{15}H_{25}O_5N$ Ethyl *α*-carbethoxy-*γ*-cyano-*β*-ethoxymethyl-*α*-ethylbutyrate, 1062.
Ethyl *α*-cyano-*β*-ethoxymethyl-*α*-ethylglutarate, 1062.
$C_{15}H_{26}O_7S_3$ Camphorsulphonylbisethylsulphonylmethane, 1512.
$C_{15}H_{27}O_4N$ Ethyl piperidyl-1-*β*-propionate-2-*α*-propionates, and their picrolonates, 968.
Ethyl 2:2:5:5-tetramethylpyrrolidine-3-carboxylate-1-acetate, 1525.
$C_{15}H_{29}O_3N$ 13-Methylamino-4-ketotetradecoic acid, hydrochloride of, 715.
$C_{15}H_{31}O_3N$ 13-Methylamino-4-hydroxytetradecoic acid, 715.

15 IV

$C_{15}H_6O_2N_2Cl_4$ Tetrachloro-*N*-benzylideneaminophthalimide, 33.
$C_{15}H_8O_2N_2Cl_2$ 3:6-Dichloro-*N*-benzylideneaminophthalimide, 32.
$C_{15}H_8O_4N_6S_3$ *NN*′-Dithiocarbamidobis-*p*-nitrophenylthiourea, 1362.
$C_{15}H_9O_3N_3Cl_2$ 2-(2′:6′-Dichloro-4′-nitrophenylamino)-3-methylene*iso*indolinone, 104.
$C_{15}H_{10}O_3N_3Cl$ 2-(2′-Chloro-4′-nitrophenylamino)-3-methylene*iso*indolinone, 103.
2-(4′-Chloro-2′-nitrophenylamino)-3-methylene*iso*indolinone, 103.
$C_{15}H_{10}O_3N_3Br$ 2-(2′-Bromo-4′-nitrophenylamino)-3-methylene*iso*indolinone, 104.
$C_{15}H_{12}ON_3Cl$ 2-(4′-Chloro-2′-aminophenylamino)-3-methylene*iso*indolinone, 103.
4′-Chloro-2′-amino-3-phenyl-1-methylphthalaz-4-one, 98.
$C_{15}H_{15}O_3NS$ *N*-Acetyl-*p*-toluenesulphonanilide, 1118.
$C_{15}H_{15}O_4NS$ 4-*p*-Toluenesulphonamido-*ω*-hydroxyacetophenone, 454.
$C_{15}H_{15}O_5NS$ 2′-Nitrophenyl-2-hydroxy-3:5-dimethylbenzylsulphone, 1351.
$C_{15}H_{16}O_2N_6S$ *s*-Diphenyldiureidothiourea, 1361.
$C_{15}H_{16}O_4N_2S$ 2-Methoxy-*m*-tolubenzenesulphonhydrazide, 261.
$C_{15}H_{18}NIS_2$ 2-Thianthrenyltrimethylammonium iodide, 1593.

15 V

$C_{15}H_{14}O_5NClS$ 4-Chloro-2′-nitro-6-methylsulphonyl-3:5-dimethyldiphenyl ether, 1020.
$C_{15}H_{21}O_2N_4BrS$ *O*-Acetyl-2-methylaneurin bromide, hydrobromide of, 1507.

C_{16} Group.

$C_{16}H_{12}$ 1:2-Dihydropyrene, and its picrate, 1302.
$C_{16}H_{14}$ 1:2:6:7-Tetrahydropyrene, 1303.
$C_{16}H_{18}$ *α*-Phenyl-*α*-tolylpropanes, 1758.
$C_{16}H_{20}$ Decahydropyrenes, 1304.

16 II

$C_{16}H_8O_4$ 7-Hydroxy-1′-ketoindeno(2′:3′:3:4)coumarin, 741.
$C_{16}H_8O_6$ Anthraquinone-1:8-dicarboxylic acid, 537.

$C_{16}H_{10}O_5$ Dibenzfuryl-3-methylenemalonic acid, 780.
5:7-Dihydroxychromeno-(3':4':2:3)-chromone, 1542.
$C_{16}H_{12}O_2$ 6-Phenyl-2-methylchromone, 772.
$C_{16}H_{12}O_3$ Methyl β-dibenzfuran-3-acrylate, 779.
Tetrahydrophenanthrenedicarboxylic anhydrides, 1318.
$C_{16}H_{12}O_4$ 9:10-Dihydrophenanthrene-4:5-dicarboxylic acid, 1304.
$C_{16}H_{12}O_5$ Brazilein, constitution of, 43.
Rubroglaucin, 86.
$C_{16}H_{12}O_8$ Naphthapurpurin triacetate, 1600.
$C_{16}H_{13}N_3$ 2':4-Anhydro-2'-amino-3-phenyl-1:4'-dimethylphthalaz-4-one, 98.
$C_{16}H_{14}O$ 1-Methoxy-2-methylphenanthrene, 262.
3-Methoxy-1-methylphenanthrene, 512.
4-Methoxy-1-methylphenanthrene, 266.
5-Methoxy-1-methylphenanthrene, 941.
8-Methoxy-1-methylphenanthrene, 1621.
$C_{16}H_{14}O_3$ 2'-Hydroxy-4'-methoxy-3-phenylindan-1-one, 741.
$C_{16}H_{14}O_4$ 2:4'-Dihydroxy-3'-methoxychalkone, 422.
1:2:3:4-Tetrahydrophenanthrene-1:2-dicarboxylic acid, 1318.
$C_{16}H_{14}O_5$ 2:4:4'-Trihydroxy-3'-methoxychalkone, 422.
$C_{16}H_{14}O_6$ 2:3:4:4'-Tetrahydroxy-3'-methoxychalkone, 423.
Triacetoxynaphthalenes, 1861.
$C_{16}H_{14}O_7$ Phenoxyacetic acid-2-phloracetophenone, 1542.
$C_{16}H_{14}S_3$ Di(phenylthio)divinyl sulphide, 769.
$C_{16}H_{15}I$ 9-Fluorenyldimethylcarbinyl iodide, 1743.
$C_{16}H_{16}O$ 8-Methoxy-1-methyl-3:4-dihydrophenanthrene, 1621.
$C_{16}H_{16}O_2$ *αγ*-Diphenyl-*n*-butyric acid, 1016.
$C_{16}H_{16}O_3$ 1-Keto-5:9-dimethoxy-1:2:3:4-tetrahydrophenanthrene, 939.
4-Methoxy-*ω*-salicylacetophenone, 42.
$C_{16}H_{16}O_5$ *β*-(4:8-Dimethoxy-1-naphthoyl)propionic acid, 938.
2-Hydroxy-4:3':4'-trimethoxybenzophenone, 741.
$C_{16}H_{16}O_6$ Dihydroxanthoxyletin-3-carboxylic acid, 292.
Dihydro*allo*xanthoxyletin-3-carboxylic acid, 1549.
$C_{16}H_{18}O_2$ *α*-Ethylhydrobenzoin, 1048.
$C_{16}H_{18}O_3$ *β*-Benzylideneacetonyl-*α*-ethyl-*γ*-butyrolactones, 1063.
$C_{16}H_{18}O_4$ *γ*-(4:8-Dimethoxy-1-naphthyl)butyric acid, 939.
$C_{16}H_{20}O_3$ Methyl *γ*-6-methoxy-3:4-dihydro-1-naphthylbutyrate, 63.
1-Phenacyl*cyclo*hexane-1-acetic acid, 1016.
1-Phenacyl-3-methyl*cyclo*pentane-1-acetic acid, 1015.
$C_{16}H_{20}O_4$ Acid, from oxidation of sulphocamphylic acid, 459.
$C_{16}H_{20}O_5$ *O*-Methyldihydro*allo*xanthoxyletinic acid, 1548.
$C_{16}H_{22}O$ 1-*β*-*o*-Anisylethyl-2-methyl*cyclo*hexene, 1621.
1-*β*-(4'-Methoxy-*o*-tolyl)ethyl-Δ^1-*cyclo*hexene, 265.
1-*β*-(5'-Methoxy-*o*-tolyl)ethyl-Δ^1-*cyclo*hexene, 511.
$C_{16}H_{22}O_2$ 1-*β*-Phenylethyl*cyclo*hexane-1-acetic acid, 1016.
$C_{16}H_{22}O_5$ *O*-Methyltetrahydro*allo*xanthoxyletinic acid, 1548.
$C_{16}H_{24}O_2$ 1-*β*-*o*-Anisylethyl-2-methyl*cyclo*hexan-1-ol, 1621.
Ethyl *β*-cuminylbutyrate, 763.
1-*β*-(4'-Methoxy-*o*-tolyl)ethyl*cyclo*hexan-1-ol, 265.
$C_{16}H_{24}O_3$ Di*cyclo*hexylsuccinic anhydrides, 1452.
$C_{16}H_{26}O_3$ Ketohydnocarpic acid, 958.
$C_{16}H_{26}O_4$ Di*cyclo*hexylsuccinic acids, 1450.
Ethyl *β*-Δ^1-*cyclo*hexenylethylmethylmalonate, 822.
$C_{16}H_{26}O_5$ Methyl *cyclo*hexanone-2:6-*ββ'*-dipropionate, 946.
$C_{16}H_{28}O_3$ Ethyl 2-methyl-1-(*δ*-ethoxybutyl)-Δ^6-*cyclo*hexene-2-carboxylate, 816
$C_{16}H_{30}O_3$ Ethyl 2-methyl-1-(*δ*-ethoxybutyl)*cyclo*hexane-2-carboxylate, 817.
$C_{16}H_{30}O_4$ Ethyl 1-hydroxy-2-methyl-1-(*δ*-ethoxybutyl)*cyclo*hexane-2-carboxylate, 816.
$C_{16}H_{30}O_5$ Ethyl 7-hydroxyheptoate, 373.
$C_{16}H_{35}N_3$ Tri*iso*amylguanidine, hydrochloride of, 828.

16 III

$C_{16}H_8O_8N_4$ 3:3'-Dinitro-*N*-phthalimidophthalimide, 1846.
$C_{16}H_7O_6N_3$ *N*-Nitrophthalimidophthalimides, 22.
$C_{16}H_8O_4N_2$ *N*-Phthalimidophthalimide, 20.
2:3-Phthalophthalaz-1:4-dione, 24.
$C_{16}H_{10}O_3N_4$ 2-*p*-Nitrophenylindolo(2':3':4:5)pyridaz-3-one, 473.
$C_{16}H_{10}O_4N_2$ *N*-Piperonylideneaminophthalimide, 21.
$C_{16}H_{10}O_5N_2$ *N*-Phthalimidophthalamic acid, and its silver salt, 23.
$C_{16}H_{10}O_{10}N_4$ *s*-Bis-(6-nitro-2-carboxybenzoyl)hydrazine, 31.
$C_{16}H_{11}O_3N$ 4-Benzoylhomophthalimide, 1314.
$C_{16}H_{12}O_4N_2$ *β*-Keto-*α*-cyano-*γ*-*p*-nitrophenoxy-*α*-phenylpropane, 1648.
$C_{16}H_{12}O_4Br_2$ *o*-Hydroxyphenyl *αβ*-dibromo-*β*-3:4-methylenedioxystyryl ketone, 1804.
$C_{16}H_{12}O_6N_2$ *S*-Dibenzoylhydrazine-2:2'-dicarboxylic acid, and its salts, 23.

$C_{16}H_{13}ON$ Phenyl-2-quinolylcarbinol, 1725.
Phenyl-1-*iso*quinolylcarbinol, 1725.
$C_{16}H_{13}O_3N$ Benzyloxyindole-2-carboxylic acids, 1727.
$C_{16}H_{13}O_3N_3$ 3-Acetamido-*N*-anilinophthalimide, 30.
2-(2′-Nitro-4′-methylphenylamino)-3-methylene*iso*indolinone, 102.
$C_{16}H_{13}O_6N$ 2-Nitro-4-benzyloxyphenylpyruvic acid, 1727.
2-Nitro-5-benzyloxyphenylpyruvic acid, 403.
$C_{16}H_{15}ON_3$ 2′-Amino-3-phenyl-1:4′-dimethylphthalaz-4-one, 98.
$C_{16}H_{15}O_6N$ δ-Phthalimido-α-carbethoxy-γ-valerolactone, 1167.
$C_{16}H_{16}O_7N_4$ 2:6-Dihydroxy-4-ethoxy-3-methylbenzaldehyde 2:4-dinitrophenylhydrazone, 289.
$C_{16}H_{16}N_3I$ 1:1′-Dimethyl-2-pyrido-2′-azacyanine iodide, 909.
2-2′-Pyridylaminoquinoline ethiodide, 909.
$C_{16}H_{17}ON_3$ αβ-Diphenylpropaldehyde semicarbazone, 548.
$C_{16}H_{17}O_2N_3$ 1-Keto-8-methoxytetrahydrophenanthrene semicarbazone, 1621.
Phenylacetylphenylcarbinol semicarbazone, 548.
$C_{16}H_{18}O_3S$ *p*-Tolyl-2-hydroxy-3:5-dimethylbenzylsulphone, 1351.
$C_{16}H_{18}O_4N_2$ Methyl 2-keto-3-methyl-2:3-dihydro-β-carboline-4-orthoformate, 471.
$C_{16}H_{18}O_4N_4$ 5-Ketomethyl-$\Delta^{4:9}$-tetrahydrohydrindene 2:4-dinitrophenylhydrazones, 59.
$C_{16}H_{19}O_2N_3$ 1-Keto-7-methoxyhexahydrophenanthrene, 65.
$C_{16}H_{19}O_5I$ 6-Iodo-3:5-benzylidene acetoneglucose, 253.
$C_{16}H_{20}O_4N_4$ Phellendral 2:4-dinitrophenylhydrazone, 988.
d-Phellendral 2:4-dinitrophenylhydrazone, 1449.
$C_{16}O_{20}O_6N_4$ Diethyl α-ketoadipate 2:4-dinitrophenylhydrazone, 811.
$C_{16}H_{20}N_2S_2$ Bis-(*p*-dimethylaminophenyl) disulphide, 1633.
$C_{16}H_{21}O_2N_3$ α-Pinene nitrosonitrolanilide, 375.
$C_{16}H_{21}O_3N_3$ 1-Phenacyl*cyclo*pentane-1-acetic acid semicarbazone, 1015.
$C_{16}H_{21}O_4N$ Ethyl 1-keto-1:2-dihydro*iso*quinoline-3-orthoformate, 475.
$C_{16}H_{22}O_7S$ 3-*p*-Toluenesulphonyl acetone 5-methyl xylose, 1601.
5-*p*-Toluenesulphonyl acetone 3-methyl xylose, 1603.
$C_{16}H_{23}ON$ Δ^{8}-*n*-Nonenoic acid *p*-toluidide, 1974.
$C_{16}H_{23}O_3N_3$ α-Terpineol nitrosonitrolanilide, 375.
$C_{16}H_{23}O_4N$ Ethyl 7-hydroxyheptoate phenylurethane, 373.
$C_{16}H_{25}ON$ *p*-Acetamido-*sec.*-octylbenzene, 1123.
$C_{16}H_{25}ON_3$ 1:10-Dimethyl-7-*iso*propenyl-$\Delta^{1(9)}$-octal-2-one semicarbazone, 1578.
$C_{16}H_{25}O_2N$ ε-Phenoxy-β-2-piperidyl-*n*-amyl alcohol, 969.
$C_{16}H_{25}O_3N$ *N*-9-Carbethoxynonoylpyrrole, 717.
Ethyl 9-2′-pyrroylnonoate, 717.
$C_{16}O_4N_2Cl_8$ Octachloro-*N*-phthalimidophthalimide, 33.

16 IV

$C_{16}H_4O_4N_2Cl_4$ 3:6:3′:6′-Tetrachloro-*N*-phthalimidophthalimide, 32.
$C_{16}H_8O_6N_2Cl_4$ *s*-Bis-(3:6-dichloro-2-carboxybenzoyl)hydrazine, 32.
$C_{16}H_{12}O_2N_3Cl$ 4′-Chloro-2′-acetamido-3-phenylphthalaz-4-one, 97.
$C_{16}H_{14}O_2Cl_2S$ Dehydro-5-chloro-*p*-2-xylenol 3-sulphide, 1021.
$C_{16}H_{14}O_6NBr$ α-Bromo-δ-phthalimido-α-carbethoxy-γ-valerolactone, 1168.
$C_{16}H_{16}O_4N_6Ni$ Nickel salicylidenesemicarbazone, 2003.
$C_{16}H_{17}O_3NS$ *N*-Acetyl-*p*-toluenesulphontoluidides, 1118.
$C_{16}H_{17}O_5NS$ 2-Nitro-6-methylsulphonyl-2:4:5-trimethyldiphenyl ether, 1020.
$C_{16}H_{17}O_7N_3S$ Benzylmethylethylsulphonium picrate, 871.
$C_{16}H_{18}O_3Cl_2S_2$ 2:5-Dichlorophenyl camphorthiolsulphonate, 489.
$C_{16}H_{18}O_4N_2S$ Phenazine ethosulphate, 1710.
$C_{16}H_{18}O_7N_2S$ 2:4-Dinitrophenyl-10-camphorylsulphone, 489.
$C_{16}H_{19}N_2IS$ 3:1′-Diethylthiazolo-2′-azacyanine iodide, 910.

16 V

$C_{16}H_{15}O_2NBr_2S$ 4:6-Dibromo-5-*p*-toluenesulphonamidohydrindene, 1107.
$C_{16}H_{15}O_2Cl_2SNa$ Sodium chloroxylenol sulphides, 1021.
$C_{16}H_{18}O_2NClS$ *p*-Toluenesulphonbenzyl-*p*-chloroethylamide, 1469.
$C_{16}H_{28}O_2NSP$ Tri-*n*-propylphosphine-*p*-toluenesulphonylimine, 535.

C_{17} Group.

$C_{17}H_{10}O_4$ 1′-Keto-7-methoxyindeno(2′:3′:3:4)coumarin, 741.
$C_{17}H_{12}O_5$ 7-Hydroxy-3′:4′-methylenedioxy-2-methyl*iso*flavone, 806.
$C_{17}H_{14}O_3$ 7-Benzyloxy-4-methylcoumarin, 1534.
1-Methoxy-2-methylphenanthrene-10-carboxylic acid, 262.
3-Methoxy-1-methylphenanthrene-10-carboxylic acid, 512.
4-Methoxy-1-methylphenanthrene-10-carboxylic acid, 265.
5-Methoxy-1-methylphenanthrene-10-carboxylic acid, 941.
$C_{17}H_{14}O_4$ 7-Methoxy-1:2:3:11-tetrahydrophenanthrene-1:2-dicarboxylic anhydride, 1319.
3:4-Methylenedioxybenzoyl-*p*-toluoylmethane, 1803.

$C_{17}H_{15}N$ Tetrahydronaphthacridine, and its picrate, 1528.
Tetrahydro-α-naphthaphenanthridine, and its picrate, 1172.
$C_{17}H_{16}O$ 2-(β-1′-Naphthylethyl)-Δ^2-*cyclo*pentenone, cyclisation of, 1859.
$C_{17}H_{16}O_2$ 5:9-Dimethoxy-1-methylphenanthrene, 939.
γδ-Diphenyl-Δ^α-pentenoic acid, 548.
$C_{17}H_{16}O_3$ *O*-Acetyl-ω-salicylacetophenone, 42.
2′-Hydroxy-4′-methoxy-3-phenylindan-1-one methyl ether, 741.
$C_{17}H_{16}O_7$ Usnic acid, 894.
$C_{17}H_{18}O$ Phenyltolylethylacetaldehydes, 1757.
α-*p*-Tolylbutyrophenone, 1757.
r-Tolyl α-phenylpropyl ketones, 1759.
$C_{17}H_{18}O_2$ 2-Acetyl-2′-α-hydroxy*iso*propyldiphenyl, 118.
5:9-Dimethoxy-1-methyl-3:4-dihydrophenanthrene, 939.
7-Hydroxy-3-ketotetrahydro-1:2-*cyclo*pentanophenanthrene, 1586.
$C_{17}H_{18}O_4$ 3′:4-Dimethoxy-ω-salicylacetophenone, 42.
$C_{17}H_{18}O_5$ Methyl β-(4:8-dimethoxy-1-naphthoyl)propionate, 938.
$C_{17}H_{18}O_6$ Decarbousnic acid, 900.
$C_{17}H_{20}O_2$ 7-Hydroxy-3-ketohexahydro-1:2-*cyclo*pentanophenanthrene, 1587.
r-2-Phenyl-1-tolyl-1-ethylethylene glycols, dehydration of, 1757.
$C_{17}H_{20}O_4$ Methyl γ-(4:8-dimethoxy-1-naphthyl)butyrate, 939.
$C_{17}H_{28}O_4$ Methyl*cyclo*hexyl malonates, 1811.
$C_{17}H_{28}O_6$ Ethyl bistetrahydrofurfurylmalonate, 720.
$C_{17}H_{30}O_6$ Ethyl octane-αδθ-tricarboxylate, 821.
$C_{17}H_{30}O_7$ Ethyl α-carbethoxy-β-ethoxymethyl-α-ethylglutarate, 1062.

17 III

$C_{17}H_{12}O_2N_2$ *N*-Cinnamylideneaminophthalimide, 21.
3-Phenyl-1:2-phthalopyrazoline, 22.
$C_{17}H_{12}O_3Cl_2$ *p*-Tolyl α:6-dichloro-3:4-methylenedioxystyryl ketone, 1803.
$C_{17}H_{12}O_3Br_2$ *p*-Tolyl α:6-dibromo-3:4-methylenedioxystyryl ketone, 1803.
$C_{17}H_{12}O_5N_2$ 2-*O*-Carbomethoxybenzoylphthalaz-1:4-dione, 24.
Methyl *N*-phthalimidophthalamate, 24.
$C_{17}H_{13}O_2N$ Anisyl 2-quinolyl ketone, 1725.
$C_{17}H_{13}O_3N$ 4-Benzoyl-2-methylhomophthalimide, 1313.
5-(3′:4′-Methylenedioxyphenyl)-3-*p*-tolyl*iso*oxazole, 1804.
4-Phenylacetylhomophthalimide, 1314.
$C_{17}H_{13}O_3N_3$ Benzylidene-3-acetamido-*N*-aminophthalimide, 1844.
$C_{17}H_{13}O_3Cl$ *p*-Tolyl α-chloro-3:4-methylenedioxystyryl ketone, 1803.
p-Tolyl 6-chloro-3:4-methylenedioxystyryl ketone, 1801.
$C_{17}H_{13}O_3Cl_3$ *p*-Tolyl αβ-dichloro-β-6-chloro-3:4-methylenedioxyphenylethyl ketone, 1801.
$C_{17}H_{13}O_3Br$ *p*-Tolyl α-bromo-3:4-methylenedioxystyryl ketone, 1803.
p-Tolyl 6-bromo-3:4-methylenedioxystyryl ketone, 1801.
$C_{17}H_{13}O_3Br_3$ *p*-Tolyl αβ-dibromo-β-6-bromo-3:4-methylenedioxyphenylethyl ketone, 1801.
$C_{17}H_{13}O_4Br$ 6-Bromo-3:4-methylenedioxybenzoyl-*p*-toluoylmethane, 1804.
$C_{17}H_{14}O_2N_2$ 2-Carbomethoxyindole-3-aldehyde anil, 469.
$C_{17}H_{14}O_2Cl_2$ *p*-Tolyl α:3-dichloro-4-methoxystyryl ketone, 1802.
$C_{17}H_{14}O_2Br_2$ *p*-Tolyl α-3-dibromo-4-methoxystyryl ketone, 1803.
$C_{17}H_{14}O_3Cl_2$ *p*-Tolyl αβ-dichloro-β-3:4-methylenedioxyphenylethyl ketone, 1801.
$C_{17}H_{14}O_3Br_2$ *p*-Tolyl αβ-dibromo-β-3:4-methylenedioxyphenylethyl ketone, 1801.
$C_{17}H_{14}O_4N_4$ 2-Carbomethoxyindole-3-aldehyde *p*-nitrophenylhydrazone, 473.
$C_{17}H_{15}ON$ Phenyl-2-quinolylmethylcarbinol, 1725.
$C_{17}H_{15}O_2N$ 5-Benzyloxy-1-acetylindole, 1727.
β-Keto-α-cyano-γ-benzyloxy-α-phenylpropane, 1649.
$C_{17}H_{15}O_2Cl$ *p*-Tolyl α-chloro-4-methoxystyryl ketone, 1803.
p-Tolyl-3-chloro-4-methoxystyryl ketone, 1801.
$C_{17}H_{15}O_2Cl_3$ *p*-Tolyl αβ-dichloro-β-3-chloro-*p*-anisylethyl ketone, 1801.
$C_{17}H_{15}O_2Br$ *p*-Tolyl α-bromo-4-methoxystyryl ketone, 1803.
p-Tolyl 3-bromo-4-methoxystyryl ketone, 1801.
$C_{17}H_{15}O_2Br_3$ *p*-Tolyl αβ-dibromo-β-3-bromo-*p*-anisylethyl ketone, 1801.
$C_{17}H_{15}O_3Cl$ 3-Chloro-*p*-anisoyl-*p*-toluoylmethane, 1803.
$C_{17}H_{15}O_3Br$ 3-Bromo-*p*-anisoyl-*p*-toluoylmethane, 1803.
$C_{17}H_{15}O_4N$ α-Phenyl-γ-methylallyl *p*-nitrobenzoates, 215.
$C_{17}H_{15}O_5N$ 2-Nitro-3-methoxy-α-*o*-tolylcinnamic acid, 941.
2-Nitro-α-(2′-methoxy-*m*-tolyl)cinnamic acid, 262.
2-Nitro-α-(4′-methoxy-*o*-tolyl)cinnamic acid, 265.
2-Nitro-α-(5′-methoxy-*o*-tolyl)cinnamic acid, 512.
$C_{17}H_{16}ON_2$ ω-Methylcyanoamido-ω-benzylacetophenone, 857.
$C_{17}H_{16}O_2Cl_2$ *p*-Tolyl αβ-dichloro-β-*p*-anisylethyl ketone, 1801.
$C_{17}H_{16}O_2Br_2$ *p*-Tolyl αβ-dibromo-β-*p*-anisylethyl ketone, 1801.
$C_{17}H_{16}O_7N_4$ 5:7-Dihydroxy-2:2-dimethylchromanone 2:4-dinitrophenylhydrazone, 284.
$C_{17}H_{16}O_8N_8$ Glutardialdehyde bis-2:4-dinitrophenylhydrazone, 302.
$C_{17}H_{16}NCl$ 12-Chloro-3-*cyclo*pentylidene-2:3-dihydro-β-quinindene, 377.
$C_{17}H_{17}ON$ ω-Dimethylamino-ω-benzylideneacetophenone, 857.
12-Keto-3-*cyclo*pentylidene-2:3:5:12-tetrahydro-β-quinindene, 377.

$C_{17}H_{17}O_3N$ 2-Amino-3-methoxy-α-*o*-tolylcinnamic acid, 941.

2-Amino-α-(2′-methoxy-*m*-tolyl)cinnamic acid, 262.

2-Amino-α-(4′-methoxy-*o*-tolyl)cinnamic acid, 265.

2-Amino-α-(5′-methoxy-*o*-tolyl)cinnamic acid, 512.

$C_{17}H_{17}O_3N_3$ 2′-Hydroxy-4′-methoxy-3-phenylindan-1-*one semicarbazone*, 741.

$C_{17}H_{18}N_3I$ 1-Methyl-1′-ethyl-2-pyrido-2′-azacyanine iodide, 909.

$C_{17}H_{19}O_2N$ 5-Phenoxyvaleranilide, 725.

$C_{17}H_{20}OS_2$ β-Hydroxy-αγ-bis(benzylthio)propane, 314.

$C_{17}H_{20}O_4N_4$ 2-Ketomethyl-$\Delta^{1:9}$-octalin 2:4-dinitrophenylhydrazones, 58.

9-Methyl-1-octalone 2:4-dinitrophenylhydrazones, 822.

$C_{17}H_{20}O_5S_2$ β-*Hydroxy-αγ-bis*(*benzylsulphonyl*)*propane*, 314.

$C_{17}H_{20}O_6N_2$ Carvotanacetyl 3:5-dinitrobenzoate, 241.

dl-Δ^6-*neo*Menthen-3-yl 3:5-dinitrobenzoate, 238.

$C_{17}H_{21}O_3N$ *N*-Acetylhexahydrocarbazole-11-β-propionic acid, 945.

$C_{17}H_{21}O_3N_3$ β-Benzylideneacetonyl-β-ethyl-γ-butyrolactone semicarbazones, 1063.

$C_{17}H_{21}O_4N$ Carvotanacetyl *p*-nitrobenzoates, 240.

$C_{17}H_{21}O_5N$ Ethyl α-carbethoxy-γ-cyano-β-phenoxymethylbutyrate, 1061.

dl-1-Hydroxymenthone *p*-nitrobenzoate, 237.

$C_{17}H_{22}O_4N_4$ 2-Keto-10-methyldecalin 2:4-dinitrophenylhydrazone, 59.

Methyl-1-decalone 2:4-dinitrophenylhydrazones, 822.

$C_{17}H_{23}ON$ Benzoylcarvotanacetylamines, 241.

cis-β-Ethoxymethyl-α-ethylglutaric-*p*-tolylimide, 1062.

$C_{17}H_{23}O_3N_3$ 1-Phenacyl*cyclo*hexane-1-acetic acid semicarbazone, 1016.

1-Phenacyl-3-methyl*cyclo*pentane-1-acetic acid semicarbazone, 1015.

$C_{17}H_{23}O_5N_5$ 2-Methyl*cyclo*pentanone-3-carboxydiethylamide dinitrophenylhydrazone, 1589.

$C_{17}H_{29}O_3N_3$ Ketohydnocarpic acid semicarbazone, 958.

17 IV

$C_{17}H_{12}O_3NBr$ 5-(6′-Bromo-3′:4′-methylenedioxyphenyl)-3-*p*-tolyl*iso*oxazole, 1804.

$C_{17}H_{12}O_3ClBr$ *p*-Tolyl chlorobromo-3:4-methylenedioxystyryl ketones, 1803.

$C_{17}H_{13}O_3ClBr_2$ *p*-Tolyl αβ-dibromo-β-6-chloro-3:4-methylenedioxyphenylethyl ketone, 1801.

$C_{17}H_{13}O_3Cl_2Br$ *p*-Tolyl α-chloro-β-bromo-β-6-chloro-3:4-methylenedioxyphenylethyl ketone, 1802.

p-Tolyl αβ-dichloro-β-6-bromo-3:4-methylenedioxyphenylethyl ketone, 1801.

$C_{17}H_{14}O_2N_3Cl$ 4′-Chloro-2′-acetamido-3-phenyl-1-methylphthalaz-4-one, 98.

$C_{17}H_{14}O_2ClBr$ *p*-Tolyl chlorobromo-4-methoxystyryl ketones, 1803.

$C_{17}H_{14}O_3NBr$ *p*-Tolyl α-bromo-3:4-methylenedioxystyryl ketoxime, 1804.

$C_{17}H_{14}O_3ClBr$ *p*-Tolyl α-chloro-β-bromo-β-3:4-methylenedioxyphenylethyl ketone, 1802.

$C_{17}H_{15}O_2ClBr_2$ *p*-Tolyl α-chloro-β-bromo-β-3-bromo-*p*-anisylethyl ketone, 1802.

$C_{17}H_{15}O_2Cl_2Br$ *p-Tolyl α-chloro-β-bromo-β-3-chloro-p-anisylethyl ketone*, 1802.

p-Tolyl αβ-dichloro-β-3-bromo-*p*-anisylethyl ketone, 1801.

$C_{17}H_{16}O_2ClBr$ *p*-Tolyl α-chloro-β-bromo-β-*p*-anisylethyl ketone, 1802.

$C_{17}H_{17}O_2NI$ 4-Phenoxy-2-ethoxy-2-methylquinoline methiodide, 426.

$C_{17}H_{17}O_5NS$ 4-*p*-Toluenesulphonamido-ω-acetoxyacetophenone, 454.

$C_{17}H_{19}O_7N_3S$ Benzylmethyl-*n*-propylsulphonium picrate, 872.

$C_{17}H_{23}O_7ClS$ Chloro-*p*-toluenesulphonyl 3-methyl acetone glucose, 253.

17 V

$C_{17}H_{17}O_4N_2ClS$ 4′-Chloro-3-nitro-4-piperidinodiphenylsulphone, 244.

$C_{17}H_{22}O_2NSP$ Phenyldiethylphosphine-*p*-toluenesulphonylimine, 534.

C_{18} Group.

$C_{18}H_{18}$ 2:2′-Di-α-methylethenyldiphenyl, 118.

$C_{18}H_{20}$ Octahydro-1:2-benzanthracene, 826.

$C_{18}H_{24}$ 2-β-Phenylethyl-*cis*-$\Delta^{2:3}$-octalin, 825.

18 II

$C_{18}H_8N_4$ 2:3-Dicyanophenanthrapyrazine, 921.

$C_{18}H_{10}N_4$ 2:3-Dicyano-5:6-diphenylpyrazine, 921, 1436.

$C_{18}H_{14}O_3$ 3-Acetyl-6-phenyl-2-methylchromone, 772.

2-Methoxy-1-naphthyl benzoate, 1861.

$C_{18}H_{15}N$ 2-Amino-1:4-diphenylbenzene, 1441.

$C_{18}H_{16}O_2$ δε-Diketo-γε-diphenyl-β-methyl-Δ^{β}-pentene, 548.

Substance, from β-dimethylaminopropiophenone, methyl iodide, and potassium hydroxide, 1930.

$C_{18}H_{16}O_4$ α-Phenyl-γ-methylallyl hydrogen phthalates, 215.

$C_{18}H_{16}O_5$ β-*p*-Toluoyl-α-3:4-methylenedioxyphenylpropionic acid, 1803.

Veratrylideneacetopiperone, 839.

$C_{18}H_{18}O_2$ α-2:3:5:5′-Tetramethylcoumarano-3′:2′:2:3-coumaran, 561.

$C_{18}H_{18}O_3$ 7-Benzyloxy-2:2-dimethylchromanone, 1534.

$C_{18}H_{18}O_4$ *O*-Acetyl-4-methoxy-ω-salicylacetophenone, 42.

5-Hydroxy-7-benzyloxy-2:2-dimethylchromanone, 1539.

Methyl 1:2:3:4-tetrahydrophenanthrene-1:2-dicarboxylate, 1318.

$C_{18}H_{18}O_5$ 7-Methoxy-4-veratryl*dihydro*coumarin, 742.

$C_{18}H_{18}O_6$ Veratroylpænaols, 743.

$C_{18}H_{20}O_2$ 7-Benzyloxy-2:2-dimethylchroman, 1533.
3-Keto-7-methoxytetrahydro-1:2-*cyclo*pentanophenanthrenes, 1584.
$C_{18}H_{21}N$ Amino-4-*cyclo*hexyldiphenyls, 1441.
$C_{18}H_{22}O$ 2-Ketododecahydrochrysenes, 1583.
$C_{18}H_{22}O_2$ 2:2′-Di-α-hydroxy*iso*propyldiphenyl, 118.
3-Keto-7-methoxyhexahydro-1:2-*cyclo*pentanophenanthrenes, 1585.
$C_{18}H_{22}O_4$ 4-Hydroxy-*m*-tolylmethylpinacols, 561.
$C_{18}H_{24}O$ Hydroxydodecahydrochrysenes, 1583.
Methyl γ-[5-methoxy-2-(γ-carbomethoxybutyryl)phenyl]butyrate, 67.
$C_{18}H_{26}O$ 3-Keto-Δ[4]-hexadecahydro-1:2-benzanthracenes, 826.
2-β-Phenylethyl-*cis*-2-decalol, 825.
$C_{18}H_{28}O_5$ Ethyl 3-carbethoxy-1-methyl-4-*iso*propenyl*cyclo*hexan-2-one-1-β-propionate, 1579.
$C_{18}H_{28}O_6$ Ethyl heptane-1:3:7-tricarboxylate, 946.
$C_{18}H_{31}N$ *p*-Aminododecylbenzene, 1123.
Dodecylaniline, and its hydrochloride, 1123.
p-*n*-Hexylamino-*n*-hexylbenzene, and its hydrochloride, 1121.
$C_{18}H_{32}O_{10}$ Hexamethyl difructosan, 784.

18 III

$C_{18}H_7O_2Br$ Bromo-3′:8-keto*meso*benzanthrones, 1101.
$C_{18}H_7O_3Br$ 1′-Bromo-3′-hydroxy*meso*benzanthrone-8-carboxylic lactone, 1101.
$C_{18}H_7O_4N$ Nitro-3′:8-keto*meso*benzanthrones, 1102.
$C_{18}H_7N_2Br_3$ Tribromoacenaphthenequinonephenazine, 1762.
$C_{18}H_8O_2Br_2$ 1′:6-Dibromo-3′:8-keto*meso*benzanthrone, 1102.
$C_{18}H_8O_3Br_2$ 1′:6-Dibromo*meso*benzanthrone-8-carboxylic acid, 1102.
$C_{18}H_8O_5N_4$ Dinitro-1′:8′-naphthoylene-1:2-benziminazoles, 1766.
$C_{18}H_9O_3N$ Nitro*meso*benzanthrones, 1102.
$C_{18}H_9O_3Br$ Bromo*meso*benzanthrone-8-carboxylic acids, 1102.
$C_{18}H_9O_5N$ Nitro*meso*benzanthrone-8-carboxylic acids, 1102.
$C_{18}H_{12}O_4N_2$ 6-Nitropiperonylidene-α-naphthylamine, 836.
$C_{18}H_{12}Cl_3P$ Trichlorophenylphosphines, 533.
$C_{18}H_{13}O_2N$ Nitro-1:4-diphenylbenzenes, 1441.
$C_{18}H_{13}O_5N$ β-Keto-α-cyano-αγ-dipiperonylpropane, 839.
$C_{18}H_{14}O_2N_2$ 6-Aminopiperonylidene-α-naphthylamine, 836.
$C_{18}H_{14}O_4N_2$ β-Imino-α-cyano-αγ-dipiperonylpropane, 839.
$C_{18}H_{15}O_3N$ 4-Phenylacetyl-2-methylhomophthalimide, 1313.
2-Phenyl-4-(2′-methoxy-*m*-tolylidene)oxazolone, 261.
β-*p*-Toluoyl-α-3:4-methylenedioxyphenylpropionitrile, 1803.
$C_{18}H_{15}O_4N$ β-Keto-α-cyano-γ-benzyloxy-α-piperonylpropane, 1649.
$C_{18}H_{15}O_4Br$ *p*-Tolyl 6-bromo-β-methoxy-3:4-methylenedioxystyryl ketone, 1804.
$C_{18}H_{15}O_5Br$ β-*p*-Toluoyl-α-6-bromo-3:4-methylenedioxyphenylpropionic acid, 1803.
$C_{18}H_{15}O_6N$ 7-Nitrobenzoyloxy-2:2-dimethylchromanone, 1532.
$C_{18}H_{16}O_4N_4$ 2-Carbethoxyindole-3-aldehyde *p*-nitrophenylhydrazone, 473.
2-Nitrobenzeneazo*cyclo*pentanone-2-carboxyanilides, 812.
$C_{18}H_{16}O_4Cl_2$ *p*-Tolyl α-chloro-β-methoxy-β-6-chloro-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{18}H_{16}O_4Br_2$ *p*-Tolyl α-bromo-β-methoxy-β-6-bromo-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{18}H_{16}O_6N_2$ Methyl *s*-dibenzoylhydrazine-2:2′-dicarboxylate, 22.
$C_{15}H_{17}O_2N$ 4-Phenoxy-2-ethoxy-2-methylquinoline, 426.
β-*p*-Toluoyl-α-*p*-anisylpropionitrile, 1802.
$C_{18}H_{17}O_2N_3$ 2′-Acetamido-3-phenyl-1:4′-dimethylphthalaz-4-one, 98.
$C_{18}H_{17}O_4Cl$ *p*-Tolyl α-chloro-β-methoxy-β-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{18}H_{17}O_4Br$ *p*-Tolyl α-bromo-β-methoxy-β-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{18}H_{17}O_5Br$ *o*-Hydroxyphenyl α-bromo-β-ethoxy-β-3:4-methylenedioxystyryl ketone, 1804.
$C_{18}H_{17}O_6N_3$ Trinitro-4-*cyclo*hexyldiphenyl, 1442.
$C_{18}H_{18}ON_2$ *cyclo*Pentanone-2-carboxyanilide anil, 810.
$C_{18}H_{18}O_3Cl_2$ *p*-Tolyl α-chloro-β-methoxy-β-3-chloro-*p*-anisylethyl ketone, 1802.
$C_{18}H_{18}O_3Br_2$ *p*-Tolyl α-bromo-β-methoxy-β-3-bromo-*p*-anisylethyl ketone, 1802.
$C_{18}H_{18}O_6N_4$ 7-Hydroxy-6-formyl-2:2-dimethylchroman 2:4-dinitrophenylhydrazone, 1544.
$C_{18}H_{18}O_7N_4$ 5-Hydroxy-7-methoxy-2:2-dimethylchromanone 2:4-dinitrophenylhydrazone, 1539.
$C_{18}H_{18}O_8N_8$ δ-Acetobutaldehyde bis-2:4-dinitrophenylhydrazone, 302.
$C_{18}H_{19}ON$ 2-Benzamido-1:4-diphenylbenzene, 1441.
$C_{18}H_{19}O_2N$ Nitro-4-*cyclo*hexyldiphenyls, 1441.
4-*p*-Tolyloxy-6-ethoxy-2-methylquinoline, 426.
$C_{18}H_{19}O_2N_5$ *cyclo*Hexane-1:2-phenylhydrazone *p*-nitrophenylhydrazone, 813.
$C_{18}H_{19}O_3Cl$ *p*-Tolyl α-chloro-β-methoxy-β-*p*-anisylethyl ketone, 1802.
$C_{18}H_{19}O_3Br$ *p*-Tolyl α-bromo-β-methoxy-β-*p*-anisylethyl ketone, 1802.
$C_{18}H_{19}N_2Br_3$ 4-*cyclo*Hexyldiphenyl-4′-diazonium perbromide, 1442.
$C_{18}H_{20}O_2S$ Dehydro-ψ-cumenol sulphide, 1021.
$C_{18}H_{20}O_4N_2$ 3:3-Diacetamido-4:4′-dimethoxydiphenyl, 38.
$C_{18}H_{20}O_4N_4$ Cuminyl methyl ketone 2:4-dinitrophenylhydrazone, 763.
$C_{18}H_{20}O_5N_4$ Methyl δ-phenoxybutyl ketone 2:4-dinitrophenylhydrazone, 724.
$C_{18}H_{20}N_3I$ 1:1′-Diethyl-2-pyrido-2′-azacyanine iodide, 909.
1:2′-Diethyl-2-pyrido-1′-azacyanine iodide, 910.

$C_{18}H_{21}ON_3$ Phenyl-*p*-tolylethylacetaldehyde semicarbazone, 1757.
(Phenyltolyl)methyl ethyl ketone semicarbazones, 1757.
a-Tolylbutyrophenone semicarbazones, 1757.
$C_{18}H_{21}O_3N$ *γ*-Carbethoxyvalero-*β*-naphthylamide, 72.
Ethyl δ-phenoxy-*a*-2-pyridyl-*n*-valerate, 969.
Hexahydrocarbazole-1:11-*ββ'*-dipropionic acid, lactam, 946.
$C_{18}H_{22}O_4N_2$ Ethyl 2-keto-2:3-dihydro-*β*-carboline-4-orthoformate, 472.
$C_{18}H_{22}O_4N_4$ 1:6-*Dimethyl-Δ$^{9:10}$-4-octalone* 2:4-dinitrophenylhydrazone, 823.
$C_{18}H_{23}ON$ Dodecahydrochrysene oxime, 1583.
$C_{18}H_{24}O_2N_2$ 1:8-Di-2'-pyrroyloctane, 717.
$C_{18}H_{25}O_5N$ Jacodine, 586.
$C_{18}H_{25}O_6N$ Jacobine, and its nitrate, 585.
$C_{18}H_{25}O_6N$ Jaconine, 586.
$C_{18}H_{27}O_3N$ Ethyl δ-phenoxy-*a*-2-piperidyl-*n*-valerate, 969.

18 IV

$C_{18}H_{12}OCl_3P$ Trichlorophenylphosphine oxides, 533.
$C_{18}H_{12}O_4N_2S_2$ 2:4-Dinitro-1:5-diphenylthiobenzene, 248.
$C_{18}H_{12}O_8N_2S_2$ 2:4-Dinitro-1:5-diphenylsulphonylbenzene, 248.
$C_{18}H_{14}O_3NBr$ *β-p*-Toluoyl-*a*-6-bromo-3:4-methylenedioxyphenylpropionitrile, 1803.
$C_{18}H_{15}O_2N_3S$ Dibenzoyl-2-amino-5-methyl-1:3:4-thiadiazine, 558.
$C_{18}H_{16}O_2NCl$ 4-*p*-Chlorophenoxy-6-ethoxy-2-methylquinoline, 426.
β-p-Toluoyl-*a*-3-chloro-*p*-anisylpropionitrile, 1803.
$C_{18}H_{16}O_2NBr$ *β-p*-Toluoyl-*a*-3-bromo-*p*-anisylpropionitrile, 1802.
$C_{18}H_{18}O_3ClBr$ *p*-Tolyl *a*-bromo-*β*-methoxy-*β*-3-chloro-*p*-anisylethyl ketone, 1802.
$C_{18}H_{19}O_4N_3S$ 2:4-Dinitro-5-piperidino-4'-methyl diphenyl sulphide, 248.
$C_{18}H_{19}O_6N_3S$ 2:4-*Dinitro*-5-*piperidino*-4'-*methyldiphenylsulphone*, 248.
$C_{18}H_{20}O_4N_2S$ Nitropiperidino-4'-methyldiphenylsulphones, 245.
$C_{18}H_{20}N_3BrSe$ Benzselenazole-1-aldehyde ethobromide *p*-dimethylaminoanil, 910.
$C_{18}H_{21}O_2NS$ Piperidino-4'-methyldiphenylsulphones, 245.
$C_{18}H_{21}O_2SNa$ Sodium *ψ*-cumenol sulphide, 1021.
$C_{18}H_{22}O_4N_2S$ *m*-Nitrobenzenesulphonyl-*n*-hexylaniline, 1121.
$C_{18}H_{23}O_2NS$ *p*-Toluenesulphonamido-*n*-amylbenzene, 1120.

18 V

$C_{18}H_{11}O_6NCl_2S_2$ 1-Nitro-2:5-di-*p*-chlorobenzenesulphonylbenzene, 244.
$C_{18}H_{20}O_2NClS$ 4-Chloro-2-piperidino-4'-methyldiphenylsulphone, 245.
$C_{18}H_{23}O_4N_2ClS_2$ Di-*p*-toluenesulphonyl-*N*-*β*-chloroethylethylenediamine, 1471.
$C_{18}H_{24}O_2NSP$ *p*-Tolyldiethylphosphine-*p*-toluenesulphonylimine, 534.

C_{19} Group.

$C_{19}H_{14}$ Methyl-1:2-benzanthracenes, 395.
$C_{19}H_{18}$ Dimethyl*cyclo*pentenophenanthrene, 419.
$C_{19}H_{22}$ *β*-9-Fluorenyl-*β*-methylpentane, 1742.
$C_{19}H_{26}$ 4'-Methyldodecahydro-1:2-benzanthracene, 396.
6-Methyldodecahydrochrysene, 1584.
2-(*β*-*o*-Tolylethyl)-*Δ*$^{2:3}$-octalin, 396.

19 II

$C_{19}H_{12}O_2$ 4'-Methyl-1:2-benzanthraquinone, 396.
$C_{19}H_{14}O_2$ (1-Naphthyl)methylphthalide, 395.
$C_{19}H_{14}O_5$ 7-Methoxy-8-(*o*-carboxyphenyl)-1-naphthoic acid, 537.
$C_{19}H_{14}O_6$ 7-Acetoxy-3':4'-methylenedioxy-2-methyl*iso*flavone, 806.
$C_{19}H_{16}O_2$ Dehydro-1-(2'-hydroxy-3':5'-dimethylbenzyl)-2-naphthol, 1936.
6-Keto-2:3-epoxy-7:7-diphenyl*bicyclo*[3, 2, 0]heptane, 1838.
o-*a*-(1-Naphthyl)ethylbenzoic acid, 395.
$C_{19}H_{16}O_4$ *1:4-Diacetoxy-2-methylphenanthrene*, 262.
3:4-Diacetoxy-1-methylphenanthrene, 513.
$C_{19}H_{17}N$ Diphenyl-*p*-tolylamine, preparation of, 627.
$C_{19}H_{18}O_2$ 1-(2-Hydroxy-3:5-dimethylbenzyl)-2-naphthol, 1351.
3-Keto-1-furyl-2-methylhexahydrophenanthrene, 1587.
$C_{19}H_{18}O_3$ 2:3-Dihydroxy-6-keto-7:7-diphenyl*bicyclo*[3, 2, 0]heptane, 1839.
$C_{19}H_{18}O_6$ 4:4-Diphenylbutane-1:2:3-tricarboxylic acids, 1840.
$C_{19}H_{18}O_7$ 5-Hydroxy-3:6:7:4'-tetramethoxyflavone, 47.
$C_{19}H_{20}O$ Methyl *β*-9-fluorenyl-*β*-methyl-*n*-propyl ketone, 1740.
$C_{19}H_{20}O_2$ 2-Benzhydryl*cyclo*pentane-1-carboxylic acid, 1841.
7-Benzyloxy-2:2:4-trimethyl-*Δ*^{3}-chromen, 1534.
$C_{19}H_{20}O_4$ 7-Benzyloxy-5-methoxy-2:2-dimethylchromanone, 1539.
3:4-Dihydroxy-2-benzhydryl*cyclo*pentane-1-carboxylic acids, 1839.
$C_{19}H_{20}O_5$ *O-Acetyl-3':4-dimethoxy-ω-salicylacetophenone*, 42.
3:4:3':4'-Tetramethoxychalkone, 837.
$C_{19}H_{20}O_6$ Acid, from methyl ketomethoxyphenylheptoate and *γ*-carbomethoxybutyryl chloride, 72.

$C_{19}H_{22}O_2$ Dehydrodi-2-hydroxy-3:5:6-trimethylphenylmethane, 1936.
3-Hydroxy-1-furyl-2-methyloctahydrophenanthrene, 1587.
$C_{19}H_{22}O_3$ Auroglaucin, 83.
$C_{19}H_{22}O_5$ α-Keto-αγ-diveratrylpropane, 837.
β-Veratrylethyl 2-hydroxy-4-ethoxyphenyl ketone, 44.
$C_{19}H_{24}O$ 2-Keto-16-methyldodecahydrochrysene, 1584.
$C_{19}H_{24}O_2$ Di-2-hydroxy-3:5:6-trimethylphenylmethane, sodium salt, 1936.
3-Keto-7-methoxy-2-methylhexahydro-1:2-*cyclo*pentanophenanthrenes, 1585.
$C_{19}H_{26}O$ 7-Methoxy-2-methylhexahydro-1:2-*cyclo*pentanophenanthrene, 1586.
$C_{19}H_{26}O_7$ Ethyl α-carbethoxy-β-phenoxymethylglutarate, 1061.
$C_{19}H_{28}O$ 2-(β-*o*-Tolylethyl)-*trans*-2-decalol, 396.
$C_{19}H_{28}O_3$ Flavoglaucin, 82.
$C_{19}H_{30}O_7$ Ethyl 6-carbethoxy*cyclo*hexanone-2:6-ββ′-dipropionate, 946.
$C_{19}H_{34}O_6$ 12 : 12-Dicarboxy-13-tetrahydrofuryltridecan-1-ol, 721.
$C_{19}H_{36}O_4$ *n*-Octyl malonate, 1811.

19 III

$C_{19}H_{11}O_3Br$ Methyl 1′-bromo*meso*benzanthrone-8-carboxylate, 1101.
$C_{19}H_{13}O_3N_3$ 5-Keto-2-phenyl-4-(2′-carboxyindolylidene)-4:5-dihydroglyoxaline, and its sodium salt, 469.
$C_{19}H_{14}ON_2$ Dibenzfuran-3-aldehyde phenylhydrazone, 779.
$C_{19}H_{14}O_3N_4$ Methylphthalaz-1:4-dione-5-azo-β-naphthols, and their salts, 1844.
$C_{19}H_{14}O_5N_2$ 2-Carboxyindole-3-(α-benzamido)acrylic acid, 469.
$C_{19}H_{15}O_2N_3$ 1-*p*-Nitrobenzyl-3:4-dihydrophenazine, 1703.
$C_{19}H_{15}O_5N$ 4-(3′:4′-Methylenedioxyphenyl)acetyl-2-methylhomophthalimide, 1314.
$C_{19}H_{16}N_3Br$ 1-*p*-Bromophenyl-3-phenyl-3-benzyltriazen, 324.
$C_{19}H_{17}OBr_3$ Tribromomethyl β-9-fluorenyl-β-methyl-*n*-propyl ketone, 1744.
$C_{19}H_{17}O_3N$ 4-Phenylacetyl-2:4-dimethylhomophthalimide, 1313.
$C_{19}H_{17}O_4Br$ *p*-Tolyl 6-bromo-β-ethoxy-3:4-methylenedioxystyryl ketone, 1804.
$C_{19}H_{17}O_5N$ 4-(3′:4′-Dimethoxyphenyl)acetylhomophthalimide, 1314.
γ-Keto-α-cyano-α-veratryl-γ-piperonylpropane, 839.
$C_{19}H_{18}OBr_2$ Dibromomethyl β-9-fluorenyl-β-methyl-*n*-propyl ketone, 1744.
$C_{19}H_{18}O_4N_4$ 2-*p*-Nitrobenzeneazo*cyclo*hexanone-2-carboxyanilide, 813.
$C_{19}H_{18}O_4Cl_2$ *p*-Tolyl α-chloro-β-ethoxy-β-6-chloro-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{19}H_{18}O_4Br_2$ *p*-Tolyl α-bromo-β-ethoxy-β-6-bromo-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{19}H_{18}O_5N_2$ 5-Nitro-4-*p*-anisoxy-6-ethoxy-2-methylquinoline, 426.
4-*m*-Nitro-*p*-methoxyphenoxy-6-ethoxy-2-methylquinoline, 426.
$C_{19}H_{19}OCl$ 4-*cyclo*Hexyldiphenyl-4′-carboxylyl chloride, 1442.
$C_{19}H_{19}O_3N$ 4-*p*-Anisoxy-6-ethoxy-2-methylquinoline, 426.
Nitromethyl β-9-fluorenyl-β-methyl-*n*-propyl ketone, 1744.
$C_{19}H_{19}O_4N$ β-Keto-α-cyano-γ-benzyloxy-α-veratrylpropane, 1649.
$C_{19}H_{19}O_4Cl$ *p*-Tolyl α-chloro-β-ethoxy-β-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{19}H_{19}O_4Br$ *p*-Tolyl α-bromo-β-ethoxy-β-3:4-methylenedioxyphenylethyl ketone, 1802.
$C_{19}H_{19}O_5N$ 7-*p*-Nitrobenzoyloxy-2:2:4-trimethylchroman, 1534.
$C_{19}H_{19}O_6N$ α-Veratryl-β-piperonylpropionamide, 839.
$C_{19}H_{20}O_3N_2$ 4-*m*-Amino-*p*-methoxyphenoxy-6-ethoxy-2-methylquinoline, 426.
$C_{19}H_{20}O_3Cl_2$ *p*-Tolyl α-chloro-β-ethoxy-β-3-chloro-*p*-anisylethyl ketone, 1802.
$C_{19}H_{20}O_3Br_2$ *p*-Tolyl α-bromo-β-ethoxy-β-3-bromo-*p*-anisylethyl ketone, 1802.
$C_{19}H_{20}O_4S_2$ βδ-Benzylsulphonylethylsulphonyl-α-phenylbutadiene, 315.
$C_{19}H_{20}O_6N_4$ αγ-Benzylidenedioxy-β-acetyl-β-methylpropane 2:4-dinitrophenylhydrazone, 843.
$C_{19}H_{20}O_7N_4$ 4:6-Dimethoxy-2-*iso*propyl(β)coumaranone 2:4-dinitrophenylhydrazone, 285.
5:7-Dimethoxy-2:2-dimethylchromanone 2:4-dinitrophenylhydrazone, 284.
$C_{19}H_{21}ON$ Aminomethyl β-9-fluorenyl-β-methyl-*n*-propyl ketone, 1745.
Methyl β-9-fluorenyl-β-methyl-*n*-propyl ketoxime, 1744.
$C_{19}H_{21}O_3Cl$ *p*-Tolyl α-chloro-β-ethoxy-β-*p*-anisylethyl ketone, 1802.
$C_{19}H_{21}O_3Br$ *p*-Tolyl α-bromo-β-ethoxy-β-*p*-anisylethyl ketone, 1802.
$C_{19}H_{21}O_6N$ Substance, from rottlerin tetramethyl ether and nitrous acid, 1864.
$C_{19}H_{22}O_2N_2$ *neoapo*Quinidine, and its salts, 596.
$C_{19}H_{24}O_3N_2$ α- and β-Hydroxydihydro*apo*quinidines, and their salts, 598.
β-Hydroxydihydro*apo*quinine, and its salts, 600.
$C_{19}H_{24}O_6N_4$ Ethyl *cis*- and *trans*-2-decalone-3-carboxylate 2:4-dinitrophenylhydrazones, 824.
$C_{19}H_{25}O_6N$ Ethyl α-carbethoxy-γ-cyano-β-phenoxymethyl-α-ethylbutyrate, 1061.
$C_{19}H_{26}O_2N_2$ *epi*-C_3-Dihydroquinidine, 597.
$C_{19}H_{29}ON_3$ 3-Keto-Δ^4-hexadecahydro-1:2-benzanthracene semicarbazones, 826.
$C_{19}H_{31}O_5N_3$ Ethyl 3-carbethoxy-1-methyl-4-*iso*propenyl*cyclo*hexan-2-one-1-β-propionate semicarbazone, 1579.
$C_{19}H_{35}O_4Br$ *sec.*-Octyl bromomalonate, 1811.

19 IV

$C_{19}H_{10}ONCl_5$ *N*-Benzoylpentachlorodiphenylamine, 1956.
N-2:4-Dichlorophenylbenzimino-2:4:6-trichlorophenyl ether, 1956.
$C_{19}H_{11}O_8N_4Cl$ 5-Chloro-2′:4′-dinitro-2-*o*-nitrobenzoyloxydiphenyl ether, 41.
$C_{19}H_{11}O_8N_4I$ 5-Iodo-2′:4′-dinitro-2-*o*-nitrobenzamidodiphenyl ether, 40.
$C_{19}H_{12}ONCl_3$ *N*-Benzoyl-2:4:4′-trichlorodiphenylamine, 1955.
N-2:4-Dichlorophenylbenzimino-*p*-chlorophenyl ether, 1955.

$C_{19}H_{13}ONCl_2$ N-Benzoyl-2:4′-dichlorodiphenylamine, 1955.
N-o-Chlorophenylbenzimino-p-chlorophenyl ether, 1955.
$C_{19}H_{13}ONS_2$ Thianthrenecarboxyanilide, 444.
$C_{19}H_{18}O_3NBr$ 4-m-Bromo-p-methoxyphenoxy-6-ethoxy-2-methylquinoline, 426.
$C_{19}H_{18}O_5NCl$ Carbethoxymethylaminodihydroxyflavylium chlorides, 455.
$C_{19}H_{19}N_4BrS_2$ 2:2′-Diethyl-αβ-diazadithiacarbocyanine bromide, 910.
$C_{19}H_{20}O_3ClBr$ *p-Tolyl α-chloro-β-ethoxy-β-3-bromo-p-anisylethyl ketone*, 1802.
$C_{19}H_{22}O_2NI$ 4-p-Tolyloxy-6-ethoxy-2-methylquinoline methiodide, 426.
$C_{19}H_{23}O_2NS$ 2-Piperidinodi-p-tolylsulphone, 246.
$C_{19}H_{24}O_4N_2S$ *m-Nitrobenzenesulphonyl-n-heptylaniline*, 1122.
$C_{19}H_{25}O_2NS$ p-Toluenesulphonyl-n-hexylaniline, 1121.

19 V

$C_{19}H_{13}ONClBr$ N-Benzoyl-4-chloro-4′-bromodiphenylamine, 1956.
N-p-Bromophenylbenzimino-p-chlorophenyl ether, 1956.
$C_{19}H_{19}O_2NClI$ 4-p-Chlorophenoxy-6-ethoxy-2-methylquinoline methiodide, 426.
$C_{19}H_{19}N_4BrSSe$ 2:2′-Diethyl-βγ-diazaselenathiacarbocyanine bromide, 910.
$C_{19}H_{34}O_2NSP$ Tri-n-butylphosphine-p-toluenesulphonylimine, 535.

C_{20} Group.

$C_{20}H_{16}$ 5-Ethyl-1:2-benzanthracene, 395.
$C_{20}H_{32}$ Dacrene, identity of, with phyllocladene, 79.
Sciadopitene, identity of, with phyllocladene, 79.
$C_{20}H_{36}$ Totarane, 518.

20 II

$C_{20}H_{14}O_2$ 5-Ethyl-1:2-benzanthraquinone, 395.
$C_{20}H_{14}O_4$ Methyl 11-methoxybenzanthrone-8-carboxylate, 537.
$C_{20}H_{16}O_2$ Dibenzyl-p-benzoquinone, 58.
$C_{20}H_{16}O_5$ O-Diethylenedeoxyhæmatoxylone, 52.
$C_{20}H_{16}O_6$ 7:8:3′:4′-Bisethylenedioxy-3-benzylidenechromanone, 51.
$C_{20}H_{16}O_7$ Diethylenehæmatoxylone, 52.
Piperonylideneveratrylsuccinic acid, 836.
Rubroglaucin acetate, 87.
$C_{20}H_{16}N_4$ 2:3-Dianilinoquinoxaline, 426.
$C_{20}H_{18}O_3$ 5-(3′:4′-Methylenedioxyphenyl)-3-p-tolyl-Δ^2-*cyclo*hexenone, 1804.
$C_{20}H_{18}O_6$ 7:8:3′:4′-Bisethylenedioxy-3-benzylchromanone, 51.
O-Diethylenehæmatoxylin, 52.
$C_{20}H_{19}N$ 2:4-Dibenzylaniline, 1125.
Phenyldi-p-tolylamine, preparation of, 627.
$C_{20}H_{20}O_4$ Deoxydimethylethylbrazilone, 45.
$C_{20}H_{20}O_5$ 2:5-Diveratrylfuran, 1648.
7-Methoxy-3-(4′-methoxy-3′-ethoxybenzylidene)chromanone, 44.
$C_{20}H_{20}O_6$ Cubebin, 391.
$C_{20}H_{20}O_7$ 6:7-Dimethoxy-3-(3′:4′-dimethoxy)phenacylphthalide, 1314.
Tangeritin, synthesis of, 46.
$C_{20}H_{22}O_4$ Methyl 3:4-dihydroxy-2-benzhydryl*cyclo*pentane-1-carboxylates, 1839.
$C_{20}H_{22}O_5$ Anhydro*iso*lariciresinol, 390.
1-Keto-6:7-dimethoxy-2-veratryl-1:2:3:4-tetrahydronaphthalene, 838.
β-Veratroyl-α-veratrylpropionic acid, 837.
$C_{20}H_{24}O_5$ 7-Methoxy-3-(4′-methoxy-3′-ethoxybenzyl)chromanone, 44.
$C_{20}H_{24}O_6$ αγ-Diveratrylbutyric acid, 838.
Ethyl β-veratryl-β-(2-hydroxy-4-methoxyphenyl)propionate, 742.
Lariciresinols, 388.
$C_{20}H_{26}O_2$ αδ-Di-(4-methoxy-o-tolyl)butane, 265.
αδ-Di-(5-methoxy-o-tolyl)butane, 511.
s-p-Tolylethylpinacol, 1758.
$C_{20}H_{30}O$ Totarol, 516.
$C_{20}H_{32}O$ Dihydrototarol, 518.
$C_{20}H_{34}O$ Tetrahydrototarol, 519.
$C_{20}H_{34}O_4$ Ethyl di*cyclo*hexylsuccinates, 1452.
$C_{20}H_{35}N$ p-n-Heptylamino-n-heptylbenzene, and its salts, 1122.

20 III

$C_{20}H_{10}O_8N_4$ 4:8:4′:8′-Tetranitro-1:1′-dinaphthyl, 573.
$C_{20}H_{11}O_8N_5$ 4:8:4′:8′-Tetranitro-1:1′-dinaphthylamine, 573.
$C_{20}H_{12}O_4N_2$ 4:4′-Dinitro-2:2′-dinaphthyl, 124.
8:8′-Dinitro-1:1′-dinaphthyl, 573.
$C_{20}H_{12}O_5N_4$ 4:4′-Dinitro-2:2′-azoxynaphthalene, 984.
$C_{20}H_{13}O_3N$ 1-Hydroxy-3-phenyl-β-naphthaquinoline-2-carboxylic acid, 867.
$C_{20}H_{14}O_2N_2$ 2:3-Diphenoxyquinoxaline, 425.
$C_{20}H_{14}O_2S$ *Di-2-hydroxy-1-naphthyl sulphide*, alkali salts, 729.

$C_{20}H_{14}O_4N_2$ 2-Phenyl-4-(2′-carbomethoxyindolylidene)oxazolone, 469.
$C_{20}H_{14}O_8N_4$ 2′:4′-Dinitro-2-*o*-nitrobenzamido-5-methyldiphenyl ether, 40.
$C_{20}H_{14}N_2Cl_2$ Dibenzphenylenediamide di-imido-chlorides, 1644.
$C_{20}H_{15}O_3N$ *N*-Benzoyldiphenylamine-2-carboxylic acid, 1958.
$C_{20}H_{15}O_4Br$ Methyl 5-bromo-8-(*o*-carbomethoxyphenyl)-1-naphthoate, 1101.
$C_{20}H_{15}O_6N$ Methyl 5-nitro-8-*o*-carbomethoxyphenyl-1-naphthoate, 1102.
$C_{20}H_{16}O_2N_2$ *p*-Nitrobenzylideneaminodiphenylmethane, 1125.
$C_{20}H_{17}O_3N$ 4-Nitro-2:6-dibenzylphenol, 57.
$C_{20}H_{17}O_3Cl$ 5-(6′-Chloro-3′:4′-methylenedioxyphenyl)-3-*p*-tolyl-Δ^2-*cyclo*hexenone, 1804.
$C_{20}H_{17}O_3Br$ 5-(6′-Bromo-3′:4′-methylenedioxyphenyl)-3-*p*-tolyl-Δ^2-*cyclo*hexenone, 1804.
$C_{20}H_{18}N_2S$ *p*-Benzyl-αβ-diphenylthiourea, 1125.
$C_{20}H_{19}O_2Cl$ 5-*m*-Chloro-*p*-anisyl-3-*p*-tolyl-Δ^2-*cyclo*hexenone, 1804.
$C_{20}H_{19}O_2Br$ 5-*m*-Bromo-*p*-anisyl-3-*p*-tolyl-Δ^2-*cyclo*hexenone, 1804.
$C_{20}H_{19}O_5N$ 4-(3′:4′-Dimethoxyphenyl)acetyl-2-methylhomophthalimide, 1313.
$C_{20}H_{20}O_6N_2$ Methyl *s*-dibenzoyldimethylhydrazine-2:2′-dicarboxylate, 23.
$C_{20}H_{21}O_5N$ γ-Keto-α-cyano-αγ-diveratrylpropane, 837.
$C_{20}H_{22}O_4N_2$ β-Imino-α-cyano-αγ-diveratrylpropane, 840.
$C_{20}H_{22}O_4N_4$ 3-Methyl-7-*iso*propyl-1:2:3:4-tetral-1-one 2:4-dinitrophenylhydrazone, 763.
$C_{20}H_{22}O_7N_4$ 5:7-Dimethoxy-8-formyl-2:2-dimethylchroman 2:4-dinitrophenylhydrazone, 291.
$C_{20}H_{22}O_8N_8$ αγ-Diacetyl-β-methylpropane bis-2:4-dinitrophenylhydrazone, 302.
$C_{20}H_{22}O_{10}N_2$ Dinitro-αγ-diveratrylbutyric acid, 838.
$C_{20}H_{22}O_{11}N_4$ β-Glucovanillin 2:4-dinitrophenylhydrazone, 494.
$C_{20}H_{23}ON$ Acetamido-4-*cyclo*hexyldiphenyls, 1441.
$C_{20}H_{23}ON_3$ Methyl β-9-fluorenyl-β-methyl-*n*-propyl ketone semicarbazone, 1742.
$C_{20}H_{23}O_6N$ β-Veratroyl-α-veratrylpropionamide, 837.
$C_{20}H_{24}O_2N_2$ α-*iso*Quinidine, 597.
*neoiso*Quinidine, and its salts, 596.
ψ-Quinidine, and its salts, 596.
α- and β-*iso*Quinines, 599.
$C_{20}H_{24}O_4N_4$ 2-Keto-$\Delta^{1:12}$-dodecahydroanthracene 2:4-dinitrophenylhydrazone, 60.
$C_{20}H_{24}O_7N_4$ Ethyl *cis*-2-ketodecalyl-3-glyoxylate 2:4-dinitrophenylhydrazone, 824.
$C_{20}H_{25}O_4N$ 1-Amino-6:7-dimethoxy-2-veratryl-1:2:3:4-tetrahydronaphthalene, 838.
$C_{20}H_{26}O_2N_2$ *epi*-C_8-Dihydroquinine, and its dihydrobromide, 599.
$C_{20}H_{26}O_3N_2$ Hydroxydihydroquinidine, 598.
$C_{20}H_{26}O_4N_4$ 4:6-Dimethyl galactosazone, 1618.
$C_{20}H_{26}O_6N_4$ Ethyl 3-methyl-2-decalone-3-carboxylate 2:4-dinitrophenylhydrazones, 825.
$C_{20}H_{27}O_4N_3$ Ethyl 1-keto-7-methoxy-2-methyloctahydrophenanthrene-2-carboxylate semicarbazone, 62.
$C_{20}H_{32}O_4N_2$ Phyllocladene nitrosate, 80.
$C_{20}H_{33}ON$ *p*-Acetamidododecylbenzene, 1123.

20 IV

$C_{20}H_{10}O_4N_2Br_2$ 4:4′-Dibromo-8:8′-dinitro-1:1′-dinaphthyl, 573.
$C_{20}H_{10}O_4N_2I_2$ 4:4′-Di-iodo-3:3′-dinitro-1:1′-dinaphthyl, 124.
$C_{20}H_{11}O_2N_2Cl_3$ *N*-2-Chlorophenyl-*N*-4-chlorophenyl-*N′N′*-4-chlorophthalylhydrazine, 1956.
$C_{20}H_{12}ONBr_3$ *N*-Benzoyl-4:6:4′-tribromodiphenylamine-2-carboxylic acid, 1958.
$C_{20}H_{12}ON_2Br_2$ 5:5′-Dibromo-α-azoxynaphthalene, 1621.
$C_{20}H_{12}O_2N_2Cl_2$ 2:3-Di-*p*-chlorophenoxyquinoxaline, 425.
$C_{20}H_{12}O_2Br_2S$ Di-3-bromo-2-hydroxy-1-naphthyl sulphide, sodium salt, 729.
$C_{20}H_{12}O_4N_2S$ Dinitrodinaphthyl sulphides, 1353.
$C_{20}H_{12}O_4N_2S_2$ Dinitrodinaphthyl disulphides, 1353.
$C_{20}H_{13}O_3NCl_2$ *N*-Benzoyl-2:4-dichlorodiphenylamine-2′-carboxylic acid, 1957.
$C_{20}H_{14}ONCl_3$ *N*-*p*-Toluoyl-2:4:4′-trichlorodiphenylamine, 1955.
$C_{20}H_{14}O_3NCl$ *N*-Benzoyl-4-chlorodiphenylaminecarboxylic acids, 1957.
$C_{20}H_{15}O_6Cl_4Fe$ 6:7:7′:8′-Bisethylenedioxychromeno(4′:3′:2:3)benzopyrylium ferrichloride, 51.
$C_{20}H_{16}O_4N_2S_2$ 2:4-Dinitro-1:5-di-*p*-tolylthiobenzene, 247.
$C_{20}H_{16}O_8N_2S_2$ 2:4-Dinitro-1:5-di-*p*-tolylsulphonylbenzene, 248.
$C_{20}H_{19}O_2NS$ *p*-Toluenesulphonphenylbenzylamide, 1118.
$C_{20}H_{19}O_4Cl_4Fe$ 4′:5′-Dimethoxy-7-ethoxybrazylium ferrichloride, 44.
7:5′-Dimethoxy-4′-ethoxybrazylium ferrichloride, 45.
$C_{20}H_{19}O_7N_2Cl$ Betanidin chloride, 448.
$C_{20}H_{20}O_4N_2S_2$ 2:4-Diamino-1:5-di-*p*-tolylsulphonylbenzene, 248.
$C_{20}H_{20}O_7N_4S$ 4-Phenyl-3-*iso*amylthiazolium picrate, 363.
$C_{20}H_{21}O_5N_2I$ 4-*m*-Nitro-*p*-methoxyphenoxy-6-ethoxy-2-methylquinoline methiodide, 426.
$C_{20}H_{22}O_3NI$ 4-*p*-Anisoxy-6-ethoxy-2-methylquinoline methiodide, 426.
$C_{20}H_{27}O_2NS$ *p*-Toluenesulphonyl-*n*-heptylaniline, 1122.
$C_{20}H_{27}O_4N_3S_2$ 1:4-Di-*p*-toluenesulphonyl-1:4:7-triaza*cyclo*nonane, and its hydrochloride, 1471.
$C_{20}H_{28}O_6N_2S_2$ *NN′*-Di-*p*-toluenesulphonyl-*NN′*-bis-(β-hydroxyethyl)ethylenediamine, 1470.
$C_{20}H_{30}O_4N_4S_2$ *NN′*-Di-*p*-toluenesulphonyl-*NN′*-bis-(β-aminoethyl)ethylenediamine, and its dihydrochloride, 1471.
$C_{20}H_{32}ONCl$ Phyllocladene nitrosochloride, 80.

20 V

$C_{20}H_{26}O_4N_2Cl_2S_2$ *NN′*-Di-*p*-toluenesulphonyl-*NN′*-bis-(β-chloroethyl)ethylenediamine, 1471.

C_{21} Group.

$C_{21}H_{14}O_2$ Dehydrodi-2-hydroxy-1-naphthylmethane, 1931.
3:3-Diphenylindanedione, 628.
$C_{21}H_{16}O$ 3-Hydroxy-9-methylcholanthrene, 1828.
$C_{21}H_{16}O_2$ Di-2-hydroxy-1-naphthylmethane, alkali salts, 729.
$C_{21}H_{18}O_5$ Methyl 7-methoxy-8-(*o*-carbomethoxyphenyl)-1-naphthoate, 537.
$C_{21}H_{20}O$ *p*-Phenylphenacyl-γ-carboxypropylideneacetone, 1587.
$C_{21}H_{20}O_7$ γ-Hydroxy-α-veratroyl-γ-veratryl-$Δ^{β}$-butenolactone, 1648.
$C_{21}H_{21}N_3$ 1-*p*-Dimethylaminobenzyl-3:4-dihydrophenazine, 1703.
$C_{21}H_{21}P$ Tritolylphosphines, 530.
$C_{21}H_{22}O_4$ 6:7-Dimethoxy-1-veratryl-3-methylnaphthalene, 1648.
$C_{21}H_{22}O_6$ αβ-Diveratroylethane, 1648.
$C_{21}H_{24}O_4$ Ethyl β-3:4-dihydroxy-2-benzhydryl*cyclo*pentane-1-carboxylate, 1839.
$C_{21}H_{24}O_6$ *O*-Trimethylethyldihydrobrazileinol, 45.
$C_{21}H_{26}O_6$ δ-Keto-β-hydroxymethyl-αδ-diveratroylpropane, 1648.
*iso*Lariciresinol methyl ether, 389.
$C_{21}H_{30}O_2$ Totarol formate, 518.
$C_{21}H_{30}O_7$ Ethyl α-carbethoxy-β-phenoxymethyl-α-ethylglutarate, 1061.
$C_{21}H_{32}O$ Totaryl methyl ether, 518.
$C_{21}H_{32}O_2$ Dihydrototaryl formate, 518.

21 III

$C_{21}H_{12}O_2Br_2$ Dehydrodibromohydroxy-1-naphthylmethanes, 1935.
$C_{21}H_{13}O_2Br$ 3-Bromodehydrodi-2-hydroxy-1-naphthylmethane, 1934.
$C_{21}H_{13}O_4N$ Nitrodehydrodi-2-hydroxy-1-naphthylmethane, 1934.
$C_{21}H_{14}O_2Br_2$ Bis-(6-bromo-2-hydroxynaphthyl-1)-methane, 1350.
Dehydrodi-2-hydroxy-1-naphthylmethane 3:4-dibromide, 1934.
Dibromohydroxy-1-naphthylmethanes, 1934.
$C_{21}H_{14}O_6N_2$ αδ-Diphthalimido-γ-valerolactone, 1168.
$C_{21}H_{15}ON$ 2-Anilino-3-phenylindone, 112.
$C_{21}H_{15}O_2Br$ Bromodi-2-hydroxynaphthyl-1-methanes, 1350.
6-Bromodi-2-hydroxy-1-naphthylmethane, sodium salt, 1936.
$C_{21}H_{15}O_6B$ 4-Hydroxy*meso*benzanthrone boroacetate, 1792.
$C_{21}H_{16}O_4N_4$ α-Phenylcinnamaldehyde 2:4-dinitrophenylhydrazone, 547.
$C_{21}H_{16}O_9N_8$ *p*-Methoxyphenylglyoxal bis-2:4-dinitrophenylhydrazone, 370.
$C_{21}H_{17}O_3N$ Methyl *N*-benzoyldiphenylamine-2-carboxylate, 1958.
N-Phenylbenzimino-*o*-carbomethoxyphenyl ether, 1957.
$C_{21}H_{18}O_4N_4$ αβ-Diphenylpropaldehyde 2:4-dinitrophenylhydrazones, 548.
$C_{21}H_{18}O_5N_2$ Methyl 2-carbethoxyindole-3-(α-benzamido)acrylate, 469.
$C_{21}H_{18}O_5N_4$ 1-Keto-8-methoxytetrahydrophenanthrene 2:4-dinitrophenylhydrazone, 1621.
Phenylacetylphenylcarbinol 2:4-dinitrophenylhydrazone, 548.
$C_{21}H_{19}ON$ αβ-Diphenylpropanilide, 547.
$C_{21}H_{19}O_3N$ 4-Nitro-2:6-dibenzylphenyl methyl ether, 58.
$C_{21}H_{19}O_4N_3$ 2-Carbethoxyindole-3-(α-benzamido)acrylamide, 469.
$C_{21}H_{19}N_4I$ 1:1′-Dimethyl-αγ-diaza-2:2′-carbocyanine iodide, 911.
$C_{21}H_{21}ON$ Acetylcarvotanacetylamines, 241.
$C_{21}H_{21}O_3P$ Trianisylphosphines, 531.
$C_{21}H_{21}O_4P$ Tri-*m*-anisylphosphine oxide, 532.
$C_{21}H_{21}N_3S$ *S*-(*p*-Dimethylaminophenyl)-*NN*′-diphenyl*iso*thiocarbamide, 1633.
$C_{21}H_{22}ON_2$ 1-Keto-7-methoxyhexahydrophenanthrene phenylhydrazone, 63.
$C_{21}H_{23}O_2N$ Acetylmethyl β-9-fluorenyl-β-methyl-*n*-propyl ketoxime, 1744.
$C_{21}H_{23}O_3N$ *cis*-β-Phenoxymethyl-α-ethylglutaric-*p*-tolylimide, 1060.
$C_{21}H_{23}O_4N$ 6:7:4′:5′-Tetramethoxy-3:4:11:12-tetrahydro-1:2-benzphenanthridine, 838.
$C_{21}H_{23}O_4Cl$ 6:7-Dimethoxy-1-veratryl-3-chloromethyl-3:4-dihydronaphthalene, 1648.
$C_{21}H_{23}O_6N_3$ Cubebin semicarbazone, 391.
$C_{21}H_{24}O_4N_4$ 1:10-Dimethyl-7-*iso*propenyl-$Δ^{1(9)}$-octal-2-one 2:4-dinitrophenylhydrazone, 1579.
$C_{21}H_{25}O_3N$ 1-Formamido-6:7-dimethoxy-2-veratryl-1:2:3:4-tetrahydronaphthalene, 838.
$C_{21}H_{26}O_4N_4$ 1:10-Dimethyl-7-*iso*propenyl-$Δ^{1(9)}$-octal-2-one 2:4-dinitrophenylhydrazone, 1580.

21 IV

$C_{21}H_{14}O_3NBr_3$ *N*-*p*-Bromophenylbenzimino-4′:6′-dibromo-2′-carbomethoxyphenyl ether, 1958.
Methyl *N*-benzoyl-4:6:4′-tribromodiphenylamine-2-carboxylate, 1958.
$C_{21}H_{15}O_3NCl_2$ *N*-2:4-Dichlorophenylbenzimino-*o*-carbomethoxyphenyl ether, 1957.
Methyl *N*-benzoyl-2:4-dichlorodiphenylamine-2′-carboxylate, 1957.
$C_{21}H_{16}ON_2Br_2$ *p*-Dimethylaminophenyl-2′:7′-dibromodiphenylenemethylenenitrone, 1628.
$C_{21}H_{16}O_3NCl$ *N*-*p*-Chlorophenylbenziminocarbomethoxyphenyl ethers, 1956.
Methyl *N*-benzoyl-4-chlorodiphenylaminecarboxylates, 1956.
$C_{21}H_{16}O_4NCl$ *N*-Benzoyl-4-chloro-4′-methoxydiphenylamine-2-carboxylic acid, 1958.
$C_{21}H_{18}O_4Br_3P$ Tribromotri-*o*-anisylphosphine oxide, 532.
$C_{21}H_{21}N_4BrS$ 2:1′-Diethyl-αβ-diazathia-2′-carbocyanine bromide, 910.
$C_{21}H_{23}ON_2Br$ ω-(ε-Bromoamylcyanoamido)-ω-benzylacetophenone, 857.
$C_{21}H_{29}O_2NS$ *p*-Toluenesulphonamido-*n*-octylbenzene, 1122.
p-Toluenesulphonyl-*n*-octylaniline, 1122.

21 V

$C_{21}H_{21}N_2ISSe$ *2:2′-Diethylselenathiacarbocyanine iodide*, 911.

C_{22} Group.

$C_{22}H_{14}N_4$ *NN′*-Di-(*α*-cyanobenzylidene)-*p*-phenylenediamine, 1645.
$C_{22}H_{16}O_2$ 4-Benzoyloxy-1-methylphenanthrene, 266.
$C_{22}H_{18}O_{10}$ Tetra-acetoxyanthraquinones, 254.
$C_{22}H_{18}O$ *3-Methoxy-9-methylcholanthrene*, 1827.
$C_{22}H_{20}O_2$ 7-(6′-Methoxy-1′-naphthoyl)-4-methylhydrindene, 1827.
$C_{22}H_{20}N_4$ 2:3-Ditoluidinoquinoxalines, 426.
$C_{22}H_{22}O_3$ 2:6-Di-*p*-anisylphenol, 58.
$C_{22}H_{22}O_4$ 4:4′-Bis-(4:6-dimethyl-1:3-benzdioxinyls), 562.
$C_{22}H_{22}O_5$ Dehydroanhydro*iso*lariciresinol dimethyl ether, 1647.
$C_{22}H_{23}N_3$ Tribenzylguanidine, hydrochloride of, 828.
$C_{22}H_{24}O_6$ Methyl 4:4-diphenylbutane-1:2:3-tricarboxylates, 1840.
$C_{22}H_{26}O_4$ 6-(5-Hydroxyhydrindyl)methylpinacol, 561.
$C_{22}H_{26}O_5$ Anhydro*iso*lariciresinol dimethyl ether, 390.
$C_{22}H_{28}O_6$ Lariciresinol dimethyl ethers, 388.
$C_{22}H_{28}O_7$ *α*- and *β*-Kosins, 565.
Protokosin, 564.
$C_{22}H_{32}O_2$ *Totaryl acetate*, 518.
$C_{22}H_{39}N$ *p*-*n*-Octylamino-*n*-octylbenzene, 1122.

22 III

$C_{22}H_8O_2Br_2$ 2:7-Dibromoanthanthrone, 1103.
$C_{22}H_{12}O_4Br_2$ 6:6′-*Dibromo-1:1′-dinaphthyl-2:2′*-dicarboxylic acid, 1103.
$C_{22}H_{16}O_3N_2$ 2:4:6-Triphenoxypyrimidine, 425.
$C_{22}H_{17}O_2Cl$ 1′-Chloro-2′-keto-2-methoxy-1′:2′-dihydrodi-1-naphthylmethane, 1935.
$C_{22}H_{17}O_2Br$ 1′-Bromo-2′-keto-2-methoxy-1′:2′-dihydrodi-1-naphthylmethane, 1835.
$C_{22}H_{17}O_3N$ Ethyl hydroxyphenylnaphthaquinolinecarboxylates, 867.
$C_{22}H_{18}O_2N_2$ *2:3-Di-p-tolyloxyquinoxaline*, 425.
$C_{22}H_{18}O_4N_2$ 2:3-Di-*p*-anisoxyquinoxaline, 425.
$C_{22}H_{19}ON$ Piperidino*meso*benzanthrone, 1094.
$C_{22}H_{19}O_3N$ *N*-Benzoyl-2:4-dimethyldiphenylamine-2′-carboxylic acid, 1957.
$C_{22}H_{20}O_6N_4$ 1-Keto-5:9-dimethoxytetrahydrophenanthrene 2:4-dinitrophenylhydrazone, 939.
$C_{22}H_{21}ON$ Acetyl-2:4-dibenzylaniline, 1125.
$C_{22}H_{22}O_3N_2$ 4-Methoxy-*ω*-salicylacetophenone phenylhydrazone, 42.
$C_{22}H_{24}O_5N_4$ Anhydrogalactosazone diacetate, 1324.
Anhydroglucosazone diacetate, 1323.
$C_{22}H_{26}O_2N_2$ Dibenzoyl-*ε*-2:3:5:6-tetramethylpiperazine, 369.
Homopilopic acid di-*p*-toluidides, 1060.
$C_{22}H_{27}O_{10}N$ Bougainvillæidin, 452.
$C_{22}H_{28}O_6N_2$ *1:10-Dimethyl-7-iso*propenyl*decal-2-ol* 3:5-dinitrobenzoate, 1580.
$C_{22}H_{28}O_{10}N_2$ Glucosephenylhydrazone penta-acetate, 1324.
$C_{22}H_{33}O_2N$ Atisine, and its salts, 1642.

22 IV

$C_{22}H_{13}O_3N_2Cl_3$ 2:4:6-Tri-*p*-chlorophenoxypyrimidine, 425.
$C_{22}H_{18}O_4NCl$ *N*-*p*-Methoxyphenylbenzimino-*p*-chloro-*o*-carbomethoxyphenyl ether, 1958.
Methyl *N*-benzoyl-4-chloro-4′-methoxydiphenylamine-2-carboxylate, 1958.
$C_{22}H_{21}O_4N_2Cl$ 7-Hydroxy-8-*iso*valeryl-4-methylcoumarin *o*-chlorobenzoylhydrazone, 278.
$C_{22}H_{30}O_5NCl$ Hydroxylaudanosine methochlorides, 428.
$C_{22}H_{30}O_5NI$ Hydroxylaudanosine methiodides, 428.

C_{23} Group.

$C_{23}H_{14}O_3$ Methyl 7:8-benzo*meso*benzanthrone-4′-carboxylate, 1102.
$C_{23}H_{16}O_2$ 6-Phenyl-2-styrylchromone, 772.
$C_{23}H_{18}O_2$ 3-Acetoxy-9-methylcholanthrene, 1827.
$C_{23}H_{18}O_3$ 2-Acetoxy-2-hydroxydi-1-naphthylmethane, 1935.
$C_{23}H_{20}O_7$ Dehydrosumatrol, 501.
$C_{23}H_{22}O_4$ Diacetyl-1-(2-hydroxy-3:5-dimethylbenzyl)-2-naphthol, 1351.
$C_{23}H_{22}O_5$ 2:3-Diacetoxy-6-keto-7:7-diphenyl*bicyclo*[3, 2, 0]heptane, 1839.
Ethyl 6-(3′:4′-methylenedioxyphenyl)-4-*p*-tolyl-Δ^3-*cyclo*hexen-2-one-1-carboxylate, 1804.
$C_{23}H_{22}O_7$ Dehydrodihydrosumatrol, 502.
Sumatrol, 497.
$C_{23}H_{24}O_7$ Dehydrotetrahydrosumatrol, 502.
Dihydrosumatrol, 502.
$C_{23}H_{24}O_7$ Sumatrolic acid, 502.
$C_{23}H_{28}O_4$ *p*-Phenylphenacyl 8-ketononoate, 723.
C[illegible]H[illegible]O[illegible] Tetrahydrosumatrol, 501.

$C_{23}H_{26}O_8$ Ethyl *aβ*-diveratroylpropionate, 1647.
$C_{23}H_{26}O_9$ *allo*Dihydrotoxicarolic acid, 1541.
$C_{23}H_{44}O_5$ *aa′*-Didecoin, 1412.

23 III

$C_{23}H_{12}O_3Br_2$ Methyl dibromobenzo*meso*benzanthronecarboxylate, 1102.
$C_{23}H_{17}O_2N$ Benzoylphenyl-1-*iso*quinolylcarbinol, 1725.
$C_{23}H_{17}O_3Br$ 1′-Bromo-2′-keto-2-acetoxy-1′:2′-dihydrodi-1-naphthylmethane, 1935.
$C_{23}H_{17}O_5N_5$ Anisyl 2-quinolyl ketone 2:4-dinitrophenylhydrazone, 1725.
$C_{23}H_{18}O_8N_2$ 4-Methyl-5-ethylpyrocatechol di-*p*-nitrobenzoate, 430.
$C_{23}H_{20}ON_2$ 2-*p*-Dimethylaminoanilino-3-phenylindone, 112.
$C_{23}H_{21}O_2N$ *dl*-*a*-Phenyl-*γ*-methylallyl *p*-xenylurethane, 215.
$C_{23}H_{21}O_3N$ Methyl *N*-benzoyl-2:4-dimethyldiphenylamine-2′-carboxylate, 1957.
4-*m*-Xylylbenzimino-2′-carbomethoxyphenyl ether, 1957.
$C_{23}H_{21}O_5Cl$ Ethyl 6-(6′-chloro-3′:4′-methylenedioxyphenyl)-4-*p*-tolyl-*Δ*³-*cyclo*hexen-2-one, 1804.
$C_{23}H_{21}O_5Br$ Ethyl 6-(6′-bromo-3′:4′-methylenedioxyphenyl)-4-*p*-tolyl-*Δ*³-*cyclo*hexen-2-one-1-carboxylate, 1804.
$C_{23}H_{22}O_4N_4$ Phenyltolylethylacetaldehyde 2:4-dinitrophenylhydrazones, 1757.
r-*m*-Tolyl *a*-phenylpropyl ketone 2:4-dinitrophenylhydrazone, 1759.
$C_{23}H_{22}O_5N_2$ Ethyl 2-carbethoxyindole-3-(*a*-benzamido)acrylate, 469.
$C_{23}H_{23}O_4Cl$ Ethyl 6-*m*-chloro-*p*-anisyl-4-*p*-tolyl-*Δ*³-*cyclo*hexen-2-one-1-carboxylate, 1804.
$C_{23}H_{23}O_4Br$ Ethyl 6-*m*-bromo-*p*-anisyl-4-*p*-tolyl-*Δ*³-*cyclo*hexen-2-one-1-carboxylate, 1804.
$C_{23}H_{23}O_7N$ Sumatrol oxime, 501.
Toxicarol oxime, 1540.
$C_{23}H_{23}N_4I$ 1:1′-Diethyl-*aγ*-diaza-2:2′-carbocyanine iodide, 911.
$C_{23}H_{24}O_3N_2$ 3′:4-Dimethoxy-*ω*-salicylacetophenone phenylhydrazone, 42.
$C_{23}H_{25}ON$ 2-Dimethylamino-1-hydroxy-1:1:3-triphenylpropane, 856.
$C_{23}H_{25}N_3S$ *S*-(*p*-Diethylaminophenyl)-*NN′*-diphenyl*iso*thiocarbamide, 1633.
$C_{23}H_{26}O_6N_4$ *l*-Arabinosazone triacetate, 1323.
d-Xylosazone triacetate, 1323.
$C_{23}H_{26}O_8S$ 6-*p*-Toluenesulphonyl 3:5-benzylidene acetone glucose, 253.
$C_{23}H_{30}O_{10}N_2$ Fructosemethylphenylhydrazone penta-acetate, 1324.
Glucosemethylphenylhydrazone penta-acetate, 1325.
$C_{23}H_{30}O_{10}S_2$ 2:3-Di-*p*-toluenesulphonyl 4:6-dimethyl *β*-methylglucoside, 1716.

23 IV

$C_{23}H_{23}N_2IS$ 2:1′-Diethylthia-2′-carbocyanine iodide, 910.
$C_{23}H_{28}O_3N_2S$ *d*-*o*-(2-Dimethylaminophenyl)phenyltrimethylammonium benzenesulphonate, 89.

C_{24} Group.

$C_{24}H_{10}N_{16}$ Tetrapyrazinoporphyrazine, 921.
$C_{24}H_{14}O_2$ 7:7′-Diacenaphthenonyl, 1763.
$C_{24}H_{16}O_7$ 7-Benzyloxy-3′:4′-methylenedioxy*iso*flavone-2-carboxylic acid, 807.
$C_{24}H_{21}O_7$ Dehydrodihydrotoxicarol methyl ether, 1540.
$C_{24}H_{26}O_4$ 4:4′-Bis-(4-methyl-7:6-trimethylene-1:3-benzdioxinyl), 561.
p-Phenylphenacyl *γ*-2-keto*cyclo*hexylbutyrate, 821.
$C_{24}H_{28}O_4$ *p*-Phenylphenacyl 9-ketodecoate, 723.
$C_{24}H_{28}O_8$ Diformyl*iso*lariciresinol dimethyl ether, 1647.
$C_{24}H_{28}O_9$ Dihydrotoxicarolic acid methyl ether, 1540.
$C_{24}H_{30}O_5$ Anhydro*iso*lariciresinol diethyl ether, 390.
Ethyl di(phenoxypropyl)acetoacetate, 724.
$C_{24}H_{32}O_6$ Lariciresinol diethyl ethers, 389.
$C_{24}H_{32}O_7$ *iso*Olivil diethyl ether, 273.
$C_{24}H_{32}N_2$ Diamino-4:4′-di*cyclo*hexyldiphenyl, 1443.

24 III

$C_{24}H_8N_{16}Cu$ Copper tetrapyrazinoporphyrazine, 921.
$C_{24}H_{16}O_4Br_2$ Methyl 6:6′-dibromo-1:1′-dinaphthyl-2:2′-dicarboxylate, 1103.
$C_{24}H_{18}O_2S$ Di-(*β*-naphthyloxy)divinyl sulphide, 769.
$C_{24}H_{22}O_7N_4$ 5-Hydroxy-7-benzyloxy-2:2-dimethylchromanone 2:4-dinitrophenylhydrazone, 1539.
$C_{24}H_{24}O_4N_2$ Bis*cyclo*pentanone-2-carboxybenzidide, 810.
$C_{24}H_{24}O_{12}N_4$ *dl*-Menthan-1:3-diol 3:5-dinitrobenzoate, 238.
$C_{24}H_{27}ON$ 2-Dimethylamino-1-hydroxy-1:1:3-triphenylbutane, 857.
$C_{24}H_{28}O_4N_2$ Dinitro-4:4′-di*cyclo*hexyldiphenyl, 1442.
$C_{24}H_{28}O_6N_4$ *l*-Rhamnosazone triacetate, 1323.
$C_{24}H_{30}O_4N_4$ 3-Keto-*Δ*⁴-hexadecahydro-1:2-benzanthracene 2:4-dinitrophenylhydrazones, 826.

24 IV

$C_{24}H_8N_8S_4Cu$ Copper tetra-2:3-thiophenoporphyrazine, 917.
$C_{24}H_{60}I_4P_4Ag_4$ Tetrakis(iodotriethylphosphine silver), 1831.
$C_{24}H_{60}I_4Ag_4As_4$ Tetrakis(iodotriethylarsinesilver), 1831.

C_{25} Group.

$C_{25}H_{22}O_8$ Dehydrosumatrol acetate, 501.
$C_{25}H_{26}O_6$ *β*-Veratryl-*β*-(2-benzyloxy-4-methoxyphenyl)propionic acid, 742.
$C_{25}H_{28}O_3$ *p*-Phenylphenacyl *γ*-*Δ*[1]-*cyclo*hexenyl-*α*-methylbutyrate, 822.
p-Phenylphenacyl *γ*-(2-methyl-*Δ*[1]-*cyclo*hexenyl)butyrate, 821.
$C_{25}H_{48}O_5$ *αα*′-Diundecoin, 1412.

25 III

$C_{25}H_{17}O_7N_3$ Methyl-1:2-benzanthracene picrates, 395.
$C_{25}H_{18}O_4Br_2$ Di-6-bromo-2-acetoxy-1-naphthylmethane, 1935.
$C_{25}H_{20}N_2S$ *pp*′-Diphenylthiocarbanilide, 1700.
$C_{25}H_{22}ON_2$ Dehydro-1-(2′-hydroxy-3′:5′-dimethylbenzyl)-2-naphthol phenylhydrazone, 1936.
$C_{25}H_{22}O_3N_2$ 2:4:6-Tri-*p*-tolyloxypyrimidine, 425.
$C_{25}H_{22}O_6N_2$ 2:4:6-Tri-*p*-anisoxypyrimidine, 425.
$C_{25}H_{22}O_8N_8$ *ω*-Aldehydo-*γ*-keto-*α*-phenyl-*Δ*[α]-hexene bis-2:4-dinitrophenylhydrazone, 302.
$C_{25}H_{23}O_3N$ 4′-(*p*-Nitrobenzoyl)-4-*cyclo*hexyldiphenyl, 1442.
$C_{25}H_{25}ON$ Benzamido-4-*cyclo*hexyldiphenyls, 1441.
$C_{25}H_{26}O_6N_4$ Auroglaucin 2:4-dinitrophenylhydrazone, 84.
$C_{25}H_{29}N_3S$ *S*-(*p*-Di-*n*-propylaminophenyl)-*NN*′-diphenyl*iso*thiocarbamide, 1633.
$C_{25}H_{32}O_6N_4$ Flavoglaucin 2:4-dinitrophenylhydrazone, 83.

25 IV

$C_{25}H_{22}O_5NCl$ Carbethoxymethylaminodihydroxy-4-phenylflavylium chloride, 455.
$C_{25}H_{37}O_2NS$ *p*-Toluenesulphonyldodecylaniline, 1123.

25 V

$C_{25}H_{22}O_2NSP$ Triphenylphosphine-*p*-toluenesulphonylimine, 530.
$C_{25}H_{22}O_2NSAs$ Triphenylarsine-*p*-toluenesulphonylimine, 535.

25 VI

$C_{25}H_{19}O_2NCl_3SP$ Trichlorophenylphosphine-*p*-toluenesulphonylimines, 533.

C_{26} Group.

$C_{26}H_{14}O_4$ Bis-3-dibenzfuran diketone, 779.
$C_{26}H_{16}O_4$ 3-Dibenzfuroyl-3-dibenzfurylcarbinol, 779.
$C_{26}H_{16}O_5$ Bis-3-dibenzfurylglycollic acid, 779.
$C_{26}H_{20}N_2$ 1:4-Dibenzylphenazine, and its ferrichloride, 1703.
$C_{26}H_{22}O_6$ *β*-Glucosidoxy-3:4-benzpyrene, 1828.
$C_{26}H_{22}O_8$ 7-Veratroyloxy-3′:4′-dimethoxyflavone, 742.
$C_{26}H_{22}N_4$ *NN*′-Di-(*α*-aminobenzylidene)benzidine, 1644.
$C_{26}H_{28}N_4$ 1:4-Bis-*p*-aminobenzyl-1:2:3:4-tetrahydrophenazine, 1703.

26 III

$C_{26}H_{18}O_4N_4$ 1:4-Bis-*p*-nitrobenzylphenazine, 1703.
$C_{26}H_{18}N_2Cl_2$ Dibenzbenzidide di-imidochloride, 1644.
$C_{26}H_{21}O_4N$ 4:4-Diphenacyl-2-methylhomophthalimide, 1314.
$C_{26}H_{22}O_9N_2$ Ethyl *αδ*-diphthalimido-*γ*-keto-*α*-carbethoxyvalerate, 1167.
$C_{26}H_{27}O_4N$ Auroglaucin phenylurethane, 84.
$C_{26}H_{29}ON$ 2-Piperidino-1-hydroxy-1:1:3-triphenylpropane, 857.

26 IV

$C_{26}H_{18}O_6N_4Cu$ Cupric salicylidenenitroanilines, 2002.
$C_{26}H_{20}O_2N_2Ni$ Nickel salicylideneaniline, 2002.
$C_{26}H_{20}O_6N_6Cu$ Cupric salicylidene-*p*-nitrophenylhydrazone, 2002.
$C_{26}H_{22}O_2N_4Cu$ Cupric salicylidenephenylhydrazone, 2002.
$C_{26}H_{22}O_2N_4Ni$ Nickel salicylidenephenylhydrazone, 2003.
$C_{26}H_{22}O_7NCl$ 4′-Carbethoxymethylamino-3:7-dihydroxy-5-benzoyloxyflavylium chloride, 454.

26 V

$C_{26}H_{18}O_2N_2Cl_2Cu$ Cupric salicylidenechloroanilines, 2002.
$C_{26}H_{18}O_2N_2Br_2Cu$ Cupric salicylidene-*p*-bromoaniline, 2002.

C_{27} Group.

$C_{27}H_{20}O_2$ Phenyldi-2-hydroxy-1-naphthylmethane, sodium salt, 1936.
$C_{27}H_{24}O_3$ Piperonylidenemethyl *β*-9-fluorenyl-*β*-methyl-*n*-propyl ketone, 1742.
$C_{27}H_{26}O_6$ 6-Trityl 2:3-dimethyl *l*-ascorbic acid, 833.
$C_{27}H_{26}O_7$ Rottlerin, 748, 1862.
$C_{27}H_{28}O_9$ Dehydrotetrahydrosumatrol diacetate, 502.
$C_{27}H_{30}O_7$ Tetrahydrorottlerin, 1863.

$C_{27}H_{32}O_{15}$ Butrin, and its lead salt, 1563.
$C_{27}H_{44}O_{2}$ 3-Hydroxy-6-keto-Δ^{4}-cholestene, 804.
Substance, from cholestan-3:4-diol and lead tetra-acetate, 381.
$C_{27}H_{46}O_{2}$ $\Delta^{5:6}$-Cholestene-3:4-diols, 379.
$C_{27}H_{46}O_{3}$ Cholestane-3:4-diol oxides, 380.
Dihydroxy-6-ketocholestanes, 805.
$C_{27}H_{48}O_{2}$ Cholestane-3:4-diols, 381.

27 III

$C_{27}H_{19}O_{2}N$ 3:3-Diphenylindanedione-2-anil oxides, 628.
$C_{27}H_{19}O_{3}N_{3}$ Nitrodehydrodi-2-hydroxy-1-naphthylmethane phenylhydrazone, 1934.
$C_{27}H_{23}O_{3}Br$ 6-Bromopiperonylidenemethyl β-9-fluorenyl-β-methyl-*n*-propyl ketone, 1742.
$C_{27}H_{24}N_{6}S_{3}$ 1:2:4-Tris(phenylthiocarbamido)benzene, 1360.
$C_{27}H_{25}O_{5}Br$ *p*-Bromophenacyl 3:4-dihydroxy-2-benzhydryl*cyclo*pentane-1-carboxylates, 1839.
$C_{27}H_{26}O_{2}N_{2}$ Benzamido-9-benzoyl-6-methylhexahydrocarbazoles, 1129.
$C_{27}H_{33}O_{15}N$ Butrin oxime, 1563.
$C_{27}H_{46}O_{2}Br_{2}$ Cholestene-3:4-diol dibromides, 380.

27 IV

$C_{27}H_{18}ON_{2}Br_{2}$ Dehydrodi-6-bromo-2-hydroxy-1-naphthylmethane phenylhydrazone, 1935.
$C_{27}H_{21}N_{6}Br_{3}S_{3}$ 1:2:4-Tris-(4-bromophenylthiocarbamido)benzene, 1360.
$C_{27}H_{22}O_{4}N_{8}S_{3}$ *NN′*-Diphenylthiocarbamidobis-*p*-nitrophenylthiourea, 1362.
$C_{27}H_{35}O_{6}N_{3}S_{3}$ Tri-*p*-toluenesulphonyl-*N*-β-aminoethyl-*N′*-ethylethylenediamine, 1470.

C_{28} Group.

$C_{28}H_{48}$ 3-Methyl-Δ^{2}-cholestene, 419.
$C_{28}H_{50}$ 3-Methylcholestane, 419.

28 II

$C_{28}H_{14}N_{12}$ Tetra-2:3-pyridinoporphyrazine, 919.
$C_{28}H_{18}N_{4}$ *NN′*-Di-(α-cyanobenzylidene)benzidine, 1644.
$C_{28}H_{22}N_{2}$ 2:4:6-Tristyrylpyrimidine, 495.
$C_{28}H_{28}O_{6}$ Trityl trimethyl *l*-ascorbic acid, 823.
$C_{28}H_{32}O_{10}$ *iso*Lariciresinol tetra-acetate, 389.
$C_{28}H_{34}O_{4}$ Totaryl hydrogen phthalate, 518.
$C_{28}H_{34}O_{10}$ Triacetylkosins, 565.
$C_{28}H_{38}O_{4}$ *p*-Phenylphenacyl 8-hydroxy-8-methyltridecoate, 724.
$C_{28}H_{42}O_{3}$ Lumistadiene-3:6-dion-5-ol, 414.
$C_{28}H_{44}O$ Lumistadienone, 414.
α-Spinastadienone, 732.
$C_{28}H_{46}O_{2}$ α-Spinasterol oxide. 732.
$C_{28}H_{46}O_{3}$ 3-Methylsarsasapogenin, 420.
$C_{28}H_{48}O$ Lumistanone, 413.
Lumistenol, 413.
$C_{28}H_{48}O_{2}$ 3-Methoxycholestan-6-one, 408.
$C_{28}H_{48}O_{4}$ Lumistanedicarboxylic acid, 414.
$C_{28}H_{50}O$ *trans*-Cholestanyl methyl ether, 408.
3-Methylcholestan-3-ol, 419.
$C_{28}H_{50}O_{3}$ 5:6-Dihydroxy-3-methoxycholestane, 1079.

28 III

$C_{28}H_{24}O_{6}N_{2}$ 2:2′-Dinitro-4:4′-dibenzyloxydibenzyl, 1727.
$C_{28}H_{30}O_{15}N_{4}$ Tetra-acetylvanillin-β-glucoside 2:4-dinitrophenylhydrazone, 494.
$C_{28}H_{34}O_{8}N_{4}$ Fructosemethylphenylosazone tetra-acetate, 1324.
$C_{28}H_{45}ON$ Lumistadienone oxime, 414.
α-Spinastadienone oxime, 732.
$C_{28}H_{47}ON_{3}$ Coprostenone semicarbazone, 384.
$C_{28}H_{47}O_{3}N$ 6-Nitro-3-methoxy-Δ^{5}-cholestene, 408.
$C_{28}H_{49}ON$ Lumistanone oxime, 413.
$C_{28}H_{49}O_{2}N$ 3-Methoxycholestan-6-one oxime, 408.
$C_{28}H_{56}N_{4}Au_{4}$ Di-*n*-propylcyanogold, constitution of, 1690.

28 IV

$C_{28}H_{20}O_{4}N_{4}Ni_{2}$ Nickel salicylaldazine, 2003.
$C_{28}H_{24}O_{2}N_{2}Cu$ Cupric salicylidenetoluidines, 2002.
$C_{28}H_{24}O_{2}N_{2}Ni$ Nickel salicylidenetoluidines, 2002.
$C_{28}H_{24}O_{4}N_{2}Cu$ Cupric salicylideneanisidines, 2002.
$C_{28}H_{24}O_{4}N_{2}Ni$ Nickel salicylideneanisidines, 2002.
$C_{28}H_{32}O_{4}N_{2}S_{2}$ 2:4-Dipiperidino-1:5-diphenylsulphonylbenzene, 248.

28 V

$C_{28}H_{28}O_{2}NSP$ Tritolylphosphine-*p*-toluenesulphonylimines, 530.
$C_{28}H_{28}O_{2}NSAs$ Tritolylarsine-*p*-toluenesulphonylimines, 535.

$C_{28}H_{28}O_5NSP$ Trianisylphosphine-*p*-toluenesulphonylimines, 531.
$C_{28}H_{30}O_3NSP$ Hydroxytritolylphosphine-*p*-toluenesulphonamide, 531.
$C_{28}H_{30}O_6NSP$ Hydroxytrianisylphosphine-*p*-toluenesulphonamide, 532.

C_{29} Group.

$C_{29}H_{20}O_5$ 2:4′-Dibenzoyloxychalkone, 423.
$C_{29}H_{36}O_{15}$ *O*-Dimethylbutrin, 1564.
$C_{29}H_{46}O_3$ 6-Keto-3-acetoxy-Δ^4-cholestene, 804.
$C_{29}H_{46}O_4$ 6:7-Diketocholestanyl acetate, 805.
$C_{29}H_{48}O_3$ *cis*-4-Hydroxy-3-acetoxy-Δ^5-cholestene, 1080.
$C_{29}H_{56}O_5$ *αα′*-Ditridecoin, 1412.

29 III

$C_{29}H_{24}O_2N_2$ 3:3-Diphenylindanedione-2-*p*-dimethylaminoanil oxide, 628.
$C_{29}H_{28}ON_2$ 3-Dibenzfuryl-*pp′*-bis(dimethylamino)diphenylmethane, 780.
$C_{29}H_{29}ON$ 2-Dimethylamino-1-hydroxy-1:1:3:3-tetraphenylpropane, 857.
$C_{29}H_{42}O_2N_2$ *p*-Nitrobenzylideneaminocetylbenzene, 1124.
$C_{29}H_{47}O_3Br$ Bromo-6-ketocholestanyl acetates, 803.

29 IV

$C_{29}H_{20}O_2N_6S_3$ 3:5-Dithiocarbimido-1:1:7:7-tetraphenylthiocarbonyldiurea, 1361.
$C_{29}H_{45}O_2NS$ *p*-Toluenesulphonylcetylaniline, 1124.

C_{30} Group.

$C_{30}H_{22}O_6$ 2:4′-Dibenzoyloxy-3′-methoxychalkone, 422.
$C_{30}H_{26}O_6$ Bis-(4′-hydroxy)flavpinacol, 423.
$C_{30}H_{26}O_8$ Bis-(7:4′-dihydroxy)flavpinacol, 424.
$C_{30}H_{26}O_{10}$ Bis(trihydroxy)flavpinacols, 424.
$C_{30}H_{30}N_4$ 1:4-Bis-*p*-dimethylaminobenzylphenazine, 1703.
$C_{30}H_{34}O_6$ Morellins, 853.
$C_{30}H_{46}O_4$ 3-Acetoxyergostadien-6-on-5-ol, 410.
3-Acetoxylumistadien-6-on-5-ol, 411.
$C_{30}H_{48}O_3$ *α*-Spinasteryl acetate oxide, 732.
$C_{30}H_{50}O$ *α*-Amyrenol, structure of, 249.
Basseol, 989.
$C_{30}H_{50}O_2$ Lumistenyl acetate, 413.
*iso*Propylidenecholestene-3:4-diol, 380.
$C_{30}H_{50}O_3$ 6-Acetoxy-3-methoxy-Δ^4-cholestene, 1080.
$C_{30}H_{50}O_4$ Methyl Δ^5-cholestene-3:7-diol-7-acetate, 303.
$C_{30}H_{52}O_4$ Dimethyl lumistanedicarboxylate, 414.
5-Hydroxy-6-acetoxy-3-methoxycholestane, 1080.
$C_{30}H_{55}N$ *p*-Dodecylaminododecylbenzene, and its hydrochloride, 1123.

30 III

$C_{30}H_{22}O_8S_4$ 1:2:4:5-Tetraphenylsulphonylbenzene, 248.
$C_{30}H_{36}O_6N_2$ Morellin dioxime, 854.
$C_{30}H_{37}O_5N_5$ Ergosine, and its salts, 396.
Ergosinine, and its hydrochloride, 396.

30 IV

$C_{30}H_{36}O_4N_2S_2$ 2:4-Dipiperidino-1:5-di-*p*-tolylsulphonylbenzene, 248.

C_{31} Group.

$C_{31}H_{22}O_5$ 7-Benzyloxy-3′:4′-methylenedioxy-2-styryl*iso*flavone, 806.
$C_{31}H_{34}O_7$ Rottlerin tetramethyl ether, 1864.
$C_{31}H_{36}O_8$ Substance, from oxidation of rottlerin tetramethyl ether, 1864.
$C_{31}H_{38}O_7$ Tetrahydrorottlerin tetramethyl ether, 1864.
$C_{31}H_{40}O_{15}$ *O*-Diethylbutrin, 1564.
$C_{31}H_{48}O_4$ 3-Acetoxy-Δ^5-cholestenylidene-7-acetic acid, 304.
$C_{31}H_{50}O_4$ Cholestene-3:4-diol diacetates, 379.
3:6-Diacetoxy-Δ^4-cholestene, 804.
$C_{31}H_{50}O_5$ Cholestane-3:4-diol oxide diacetates, 380.
$C_{31}H_{52}O_4$ Cholestane-3:4-diol diacetates, 381.
$C_{31}H_{52}O_{14}$ Methyl tetramethoxyacetyldihydrochaulmoograte, 959.

31 III

$C_{31}H_{37}O_7N_5$ Morellin nitroguanylhydrazone, 854.

C_{32} Group.

$C_{32}H_{30}O_8$ Bis-(4′-hydroxy-3′-methoxy)flavpinacol, 422.
$C_{32}H_{30}O_{10}$ Bis-(7:4′-dihydroxy-3′-methoxy)flavpinacol, 423.
$C_{32}H_{30}O_{12}$ Bis(trihydroxy-3′-methoxy)flavpinacols, 423.
$C_{32}H_{38}O_6$ Morellin dimethyl ether, 855.
$C_{32}H_{50}O_2$ Dehydro-α-amyrenol acetate, 251.
$C_{32}H_{50}O_3$ Dehydro-α-amyrenyl acetate oxide, 251.
$C_{32}H_{52}O_2$ Basseol acetate, 990.
$C_{32}H_{52}O_5$ Methyl 3-acetoxy-Δ^5-cholesten-7-ol-7-acetate, 303.
$C_{32}H_{54}O_2$ Bassenyl acetate, 991.

32 III

$C_{32}H_{16}N_8Ni$ Nickel phthalocyanine, structure of, 219.

C_{33} Group.

$C_{33}H_{40}O_6$ Morellin trimethyl ether, 855.
$C_{33}H_{64}O_5$ *αα′-Dipentadecoin, 1413.*

33 III

$C_{33}H_{48}O_4N_4$ Coprostenone 2:4-dinitrophenylhydrazone, 384.

C_{34} Group.

$C_{34}H_{30}O_{10}$ 4′-*O*-Tetra-acetyl-β-glucosidoxy-3:4-benzpyrene, 1828.
$C_{34}H_{30}N_4$ *NN′*-Di-(α-methylanilinobenzylidene)-*p*-phenylenediamine, and its picrate, 1644.
$C_{34}H_{50}O_3$ *cis*-Cholestene-3:4-diol 3-benzoate, 380.
$C_{34}H_{66}O_3$ 13-Ketotetratriacontanoic acid, 1001.
$C_{34}H_{68}O_2$ *n*-Tetratriacontanoic acid, 1001.
$C_{34}H_{68}O_3$ α-Hydroxytetratriacontanoic acid, 1002.

34 III

$C_{34}H_{26}O_4N_4$ 4:4′-Dimethoxydiphenylene-3:3′-bisazo-β-naphthol, 38.
$C_{34}H_{30}O_8S_4$ 1:2:4:5-Tetra-*p*-tolylsulphonylbenzene, 248.
$C_{34}H_{40}O_{13}N_4$ Anhydromaltose phenylosazone penta-acetates, 1323.
$C_{34}H_{67}OCl$ Tetratriacontanoyl chloride, 1002.
$C_{34}H_{67}O_2Br$ α-Bromotetratriacontanoic acid, 1001.

34 IV

$C_{34}H_{24}O_2N_2Cu$ Cupric salicylidenenaphthylamines, 2002.
$C_{34}H_{24}O_2N_2Ni$ Nickel salicylidenenaphthylamines, 2002.
$C_{34}H_{26}O_2N_4S_2$ 4:4′-Dimethylthioldiphenylene-3:3′-bisazo-β-naphthol, 38.
$C_{34}H_{42}O_4N_4S_2$ *NN′*-Bis-(β-*p*-toluenesulphonbenzylamidoethyl)ethylenediamine, hydrochloride of 1470.

C_{35} Group.

$C_{35}H_{34}O_{10}$ 3-*O*-Tetra-acetyl-β-glucosidoxy-9-methylcholanthrene, 1828.
$C_{35}H_{50}O_2$ α-Spinasteryl benzoate, 732.
$C_{35}H_{54}O_4$ *5-Hydroxy-6-benzoyloxy-3-methoxycholestane, 1079.*

35 III

$C_{35}H_{32}O_{11}S$ 2-*p*-Toluenesulphonyl 3:5:6-tribenzoyl β-methylglucofuranoside, 253.
$C_{35}H_{53}ON_3$ Coprostenone *o*-tolylsemicarbazone, 382.

C_{36} Group.

$C_{36}H_{24}O_7$ 2:4:4′-Tribenzoyloxychalkone, 423.
$C_{36}H_{26}O_8$ 2:4:4′-Tribenzoyloxy-3′-methoxychalkone, 422.
$C_{36}H_{28}O_3$ Phenacylidenedeoxybenzoins, 846.
$C_{36}H_{34}N_4$ Di-(α-methyl-*o*-toluidinobenzylidene)-*p*-phenylenediamine, and its picrate, 1644.
$C_{36}H_{52}O_4$ 3-Benzoyloxy-6-acetoxy-Δ^4-cholestene, 1079.
Cholestenediol 3-benzoate-4-acetates, 380.
$C_{36}H_{54}O_5$ 5-Hydroxy-3-benzoyloxy-6-acetoxycholestane, 1079.
$C_{36}H_{70}O_3$ Ethyl 13-ketotetratriacontanoate, 1001.
$C_{36}H_{72}O_2$ Ethyl *n*-tetratriacontanoate, 1001.
n-Hexatriacontanoic acid, 1003.

36 III

$C_{36}H_{26}O_3Cl_2$ Phenacylidenedi(chlorodeoxybenzoins), 846.
$C_{36}H_{26}O_3Br_2$ *Phenacylidenedi-(4-bromodeoxybenzoin), 847.*
$C_{36}H_{27}O_3Br$ *p*-Bromophenacylidenedideoxybenzoins, 847.
$C_{36}H_{29}O_3N$ *p*-Aminophenacylidenedideoxybenzoin, 847.
$C_{36}H_{28}O_8N_8$ Bis-2-nitrobenzeneazo*cyclo*pentanone-2-carboxybenzidide, 812.
$C_{36}H_{38}O_6N_2$ Protocuridine, and its hydrochloride, 1478.
*neo*Protocuridine, and its hydrochloride, 1479.

36 IV

$C_{36}H_{84}I_4P_4Ag_4$ Tetrakis(iodotri-*n*-propylphosphinesilver), 1831.
$C_{36}H_{84}I_4Ag_4As_4$ Tetrakis(iodotri-*n*-propylarsinesilver), 1831.

C_{37} Group.

$C_{37}H_{30}O_3$ *p*-Methylphenacylidenedideoxybenzoins, 847.
$C_{37}H_{30}O_4$ *p*-Methoxyphenacylidenedideoxybenzoins, 847.
$C_{37}H_{52}O_2$ Dehydro-α-amyrenol benzoate, 251.
$C_{37}H_{54}O_5$ Methyl 3-benzoyloxy-Δ^5-cholesten-7-ol-7-acetate, 303.
$C_{37}H_{56}O_2$ Bassenyl benzoate, 991.
$C_{37}H_{72}O_5$ *αα'*-Diheptadecoin, 1413.

37 III

$C_{37}H_{30}N_3Cl$ *NN'N''*-Triphenylpararosaniline hydrochloride, 1632.

C_{38} Group.

$C_{38}H_{32}O_3$ Phenacylidenedi(methyldeoxybenzoins), 846.
$C_{38}H_{32}O_5$ Phenacylidenedi(4-methoxydeoxybenzoins), 846.
$C_{38}H_{38}N_4$ Di-(α-ethyl-*o*-toluidinobenzylidene)-*p*-phenylenediamine, and its picrate, 1644.
$C_{38}H_{42}O_{10}$ Morellin tetra-acetate, 854.
$C_{38}H_{71}N$ *p*-Cetylaminocetylbenzene, 1124.
$C_{38}H_{76}O_2$ *n*-Octatriacontanoic acid, 1003.

38 III

$C_{38}H_{28}N_4Cl_2$ *NN'*-Di-(α-*o*-chloroanilinobenzylidene)benzidine, and its picrate, 1644.
$C_{38}H_{46}O_{18}N_4$ Lactose phenylosazone hepta-acetate, 1322.
Maltose phenylosazone hepta-acetate, 1323.
$C_{38}H_{70}ON_2$ *p*-Cetylphenylcetylnitrosoamine, 1124.

C_{40} Group.

$C_{40}H_{34}N_4$ Di-(α-methylanilinobenzylidene)benzidine, and its picrate, 1644.
$C_{40}H_{80}O_2$ Ethyl octatriacontanoate, 1003.

40 III

$C_{40}H_{38}N_3Cl$ *NN'N''*-Triphenyl-*NN'N''*-trimethylpararosaniline hydrochloride, 1634.
$C_{40}H_{46}O_{13}N_4$ Anhydrolactose phenylosazone penta-acetate, 1322.
$C_{40}H_{73}ON$ *n*-Tetratriacontananilide, 1001.

40 IV

$C_{40}H_{48}O_6N_2I_2$ *O*-Methylprotocuridine methiodide, 1479.
O-Methyl*neo*protocuridine methiodide, 1479.

C_{41} Group.

$C_{41}H_{42}O_6$ Lariciresinol dimethyl triphenylmethyl ether, 1647.
$C_{41}H_{54}O_4$ Cholestenediol dibenzoates, 380.
3:6-Dibenzoyloxy-Δ^4-cholestene, 804, 1079.
$C_{41}H_{54}O_5$ 3:7-Dibenzoyloxy-6-ketocholestane, 805.

41 III

$C_{41}H_{50}O_{12}N_4$ *cis*-Cholestenediol bis-3:5-dinitrobenzoate, 380.

41 IV

$C_{41}H_{34}O_2N_8S_2$ 3:5-Bis(phenylthiocarbamido)-1:1:7:7-tetraphenylthiocarbonyldiurea, 1361.

C_{42} Group.

$C_{42}H_{38}N_4$ Di-(α-ethylanilinobenzylidene)benzidine, and its picrate, 1644.

42 III

$C_{42}H_{44}O_3P_2$ Tritolylphosphine oxides, 530.

C_{43} Group.

$C_{43}H_{28}O_9$ Tetrabenzoyloxychalkones, 424.

C_{44} Group.

$C_{44}H_{30}O_{10}$ Tetrabenzoyloxy-3'-methoxychalkones, 423.
$C_{44}H_{42}N_4$ Di-(α-ethyltoluidinobenzylidene)benzidines, 1644.

C_{46} Group.

$C_{46}H_{38}N_4$ Di-(α-benzylanilinobenzylidene)-*m*-phenylenediamine, 1644.
Di-(α-benzylanilinobenzylidene)-*p*-phenylenediamine, and its picrate, 1644.
$C_{46}H_{90}O_3$ 13-Ketohexatetracontanoic acid, 1004.
$C_{46}H_{92}O_2$ Hexatetracontanoic acid, 1004.

C_{47} Group.

$C_{47}H_{50}O_{25}$ Deca-acetylbutrin, 1563.

C_{48} Group.

$C_{48}H_{94}O_3$ Ethyl 13-ketohexatetracontanoate, 1004.
$C_{48}H_{96}O_2$ Ethyl hexatetracontanoate, 1004.

48 IV

$C_{48}H_{108}I_4P_4Ag_4$ Tetrakis(iodotri-*n*-butylphosphinesilver), 1831.

C_{50} Group.

$C_{50}H_{38}N_4$ Di-(α-diphenylaminobenzylidene)benzidine, and its picrate, 1644.

C_{52} Group.

$C_{52}H_{42}N_4$ Di-(α-benzylanilinobenzylidene)benzidine, and its picrate, 1644.

52 IV

$C_{52}H_{36}O_4N_4Ni_2$ Nickel disalicylidenebenzidine, 2003.

C_{53} Group.

$C_{53}H_{100}O_6$ Ethyl α-acetyl-α-tetratriacontanoylbrassylate, 1004.

C_{55} Group.

$C_{55}H_{43}ON_3$ Hexaphenyltriaminotriphenylcarbinol, 1634.
$C_{55}H_{44}O_{27}N_4$ Tetra-*p*-nitrobenzoylbutrin, 1503.

C_{57} Group.

$C_{57}H_{53}O_6N_3S_3P_2$ *NN*-Bis-(*p*-toluenesulphonamidotriphenylphosphine)-*p*-toluenesulphonamide, 530.

C_{64} Group.

$C_{64}H_{42}N_8$ Octaphenylporphyrazine, 932.

64 III

$C_{64}H_{40}N_8Cu$ Copper octaphenylporphyrazine, 932.
$C_{64}H_{40}N_8Mg$ Magnesium octaphenylporphyrazine, 931.

64 IV

$C_{64}H_{32}O_{16}N_{16}Mg$ Magnesium octa-*p*-nitrophenylporphyrazine, 932.
$C_{64}H_{39}N_8ClCu$ Copper chloro-octaphenylporphyrazine, 932.

C_{66} Group.

$C_{66}H_{134}$ *n*-Hexahexacontane, 1002.

C_{67} Group.

$C_{67}H_{136}$ *n*-Heptahexacontane, 1002.

C_{80} Group.

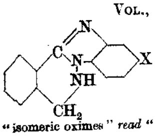
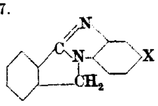
$C_{80}H_{72}O_{24}$ Nonabenzoylbutrin, 1563.

ERRATA.

Vol., 1936.

Page.	Line.	
1844	6*	*for* "acid" *read* "alkaline."
1846	31	*for* "dissolved" *read* "suspended."

Vol., 1937.

95	formula (IX)	*for*  *read* 
521	8	*for* "isomeric oximes" *read* "isomeric 3-halogenonitrosophenols."

Vol., 1937.

39	2*	*for* "*.2-hydroxy-*" *read* "*-2-amino.*"
1312	9—8*	*for* "3 : 4-dimethoxyphenyl or 3 : 4-methylenedioxyphenyl" *read* "3 : 4-dimethoxybenzyl or 3 : 4-methylenedioxybenzyl."
1576	24	*for* "F. C. McQuillin" *read* "F. J. McQuillin."

* From bottom.

SYMBOLS FOR THERMODYNAMICAL AND PHYSICO-CHEMICAL QUANTITIES AND CONVENTIONS RELATING TO THEIR USE, ADOPTED AS RECOMMENDED PRACTICE BY THE CHEMICAL SOCIETY.

(Where two or more symbols separated by commas or semicolons are given for a quantity, these symbols are to be regarded as alternatives for which no preference is expressed. On the other hand, where two symbols are separated by a dotted line, the former is the first preference.)

1. To be Printed in Black Italic.

(Certain important physical constants.)

F Faraday's constant.
J Mechanical equivalent of heat.
N Avogadro's number.
R { Gas constant per mol.
  Rydberg's constant.

c Velocity of light in vacuo.
e Electronic charge (charge equal and opposite in sign to that of an electron).
g Acceleration due to gravity (standard value, if variation from standard is significant).
h Planck's constant.
k Boltzmann's constant.
m Rest mass of an electron.

2. To be Printed in Ordinary Italic, when not Greek.

General Physics and Chemistry.

Length	} *l*
mean free path of molecules	} *l*
height	*h*
diameter, distance	*d*
diameter of molecules	σ
radius	*r*
Mass	*m*
molecular weight	*M*
atomic weight	*A*
atomic number	*Z*
gram-equivalent weight	*Z*, *J*
Time	*t*
time interval, especially half- or mean-life	τ
frequency	ν
Velocity	*v*; *c*, (***u***, ***v***, ***w***)
of ions	*u* (with subscript)
angular	ω
Acceleration	*f* . . . *a*
due to gravity (as variable)	*g*

Force	F, (X, Y, Z)
Moment of inertia	I
Pressure	p, P
especially osmotic	Π
Volume	v, V
Density	ρ . . . d
Compressibility	κ . . . K
Viscosity	η
Fluidity	ϕ
Surface area	A . . . s
Angle of contact	θ
Surface tension	γ . . . σ
Parachor	$[P]$
Surface concentration excess	Γ
Number of mols	n
Concentration, mol fraction	N, x
in other terms	c, C
Solubility	s
Diffusion coefficient	D
Chemical equilibrium constant (products/reactants)	K
solubility product	K_s . . . L
Velocity constant of chemical reaction	k
Number of molecular collisions per second	Z
Partition function	f
Efficiency, of any process	η
Wave function	ψ

Heat and Thermodynamics.

Temperature, on absolute scale, (°K)	T
on other scales	θ . . . t
Thermal conductivity	k
Energy (general symbol)	E
Work done by or on a system	w . . . W
Heat entering a system	q
Specific heat	c_p and c_v
molecular heat	C_p and C_v
Ratio of specific heats	γ
Latent heat, per g.	l
per mol	L
Intrinsic energy	U . . . E
Enthalpy, total heat, or heat content	H
Entropy	S
Free energy (Helmholtz)	A . . . F
Thermodynamic potential, Gibbs function, free energy (G. N. Lewis)	G

Vapour pressure constant	i
Chemical potential	μ
Activity	a
coefficient (for molar concentration)	f
Osmotic coefficient	g
Van 't Hoff's factor	i

Electricity.

Quantity of electricity	Q
especially electrostatic charge	e
Potential (difference)	V
Volta potential	V
electrokinetic potential	ζ
especially electromotive force of voltaic cells	E
Potential gradient, in electric field	X
Electronic exit work function	ϕ
Current	I
Resistance	R
specific resistance	ρ . . . r
specific conductance	κ . . . σ
Inductance, self	L
mutual	M
Electrostatic capacity	C
Dielectric constant	ϵ
Dipole moment	μ

Electrochemistry.

Degree of electrolytic dissociation	α
Valency of an ion	z
Ionic strength	I
Equivalent conductance	Λ
equivalent ionic conductance, "mobility"	l (with subscript)
Transport number	T (with subscript) . . . n (with subscript)
Single electrode potential	e (with subscript), E (with subscript)
Electrolytic polarisation, overvoltage	η . . . π

Magnetism.

Magnetic field strength	H
flux	ϕ
permeability	μ
susceptibility—volume	κ
mass	χ
moment	M
induction	B

Optics.

Wave length	λ
Wave number	ν
Intensity of light	I
Refractive index	n (with subscript)
	. . . μ (with subscript)
specific refraction	r (with subscript)
molecular refraction	$[R]$ (with subscript)
Molar extinction coefficient	ϵ
Angle of (optical) rotation	α
specific rotation	$[\alpha]$
Specific magnetic rotation	ω

3. To be Printed in Roman, when not Greek.

(a) *Examples of Mathematical Constants and Operators.*

Base of natural logarithms	e
Ratio of circumference to diameter . . .	π
Differential	d
partial	∂
Increment	Δ
very small increment	δ
Sum	Σ
Product	Π
Function	f, φ

(b) *Examples of single-letter abbreviations.*

*Ampère (in sub-units)	a.
Volt	v.
Ohm	Ω.
Watt	W.
Farad	F.
Henry	H.
Centigrade	C.
Fahrenheit	F.
Kelvin	K.
Ångstrom unit	A.
micron	μ.
metre	m.
gram	g.
litre	l.
Röntgen unit	r.
†Normal (concentration)	N.
†Molar (concentration)	M.

* *E.g.* " ma." for " milliampère "; but " amp." is preferred for " ampère."
† Separated by a hyphen (and no full stop) from a chemical formula which follows it.

The following prefixes to abbreviations for the names of units should be used to indicate the specified multiples or sub-multiples of these units :

M	mega-	$10^{6} \times$
k	kilo-	$10^{3} \times$
d	deci-	$10^{-1} \times$
c	centi-	$10^{-2} \times$
m	milli-	$10^{-3} \times$
μ	micro-	$10^{-6} \times$

e.g., MΩ. denotes megohm ; kw., kilowatt ; and μg., microgram. The use of μμ. instead of mμ. to denote 10^{-7} cm., or of γ to denote microgram is deprecated.

4. Subscripts and other Modifying Signs.

(a) *Subscripts to symbols for quantities.*

I, II . . . 1, 2 . . .	*especially with symbols for thermodynamic functions*, referring to different systems or different states of a system.
A, B . . .	referring to molecular species A, B, etc.
i	referring to a typical ionic species i.
u	referring to an undissociated molecule.
+, −	referring to a positive or negative ion, or to a positive or negative electrode.
p, *v*, *T*	indicating constant pressure, volume, and temperature respectively.
q	indicating adiabatic conditions.
w	indicating that no work is performed.
p, *c*, *a*	*with symbol for an equilibrium constant*, indicating that it is expressed in terms of pressure, concentration, or activity.
G, V, L, X	referring to gas, vapour, liquid, and crystalline states, respectively.
f, e, s, t, d	referring to fusion, evaporation (vaporisation of liquid), sublimation, transition, and dissolution or dilution respectively.
c	referring to the critical state or indicating a critical value.
0	referring to a standard state, or indicating limiting value at infinite dilution.
C, D, F	*with symbols for optical properties*, referring to a particular wavelength.

Where a subscript has to be added to a symbol which already carries a subscript, the two subscripts may be separated by a comma or the symbol with the first subscript may be enclosed in parentheses with the second subscript outside.

(b) *Other modifying signs.*

o	*as right-hand superscript to symbol*, referring to a standard state.
[ ]	*enclosing formula of chemical substance*, indicating its molar concentration.
{ }	*enclosing formula of chemical substance*, indicating its molar activity.

In crystallography it is recommended that:

Millerian indices be enclosed in parentheses, ( );
Laue indices be unenclosed;
Indices of a plane family be enclosed in braces, { };
Indices of a zone axis or line be enclosed in brackets, [ ].

Numerals attached to a symbol for a chemical element in various positions have the following meanings:

upper left	mass number of atom.
lower left	nuclear charge of atom.
lower right	number of atoms in molecule.

e.g., ${}^{7}_{3}Li$; ${}^{2}_{1}H_2$ (= D_2).

ALPHABETICAL INDEX OF RECOMMENDED SYMBOLS, and single-letter abbreviations.

including all those given in the above lists except prefixes, subscripts and other modifying signs.

The name of any quantity for which a given symbol is a second preference is printed in parentheses.

A free energy—Helmholtz; atomic weight; surface area.
A. Ångstrom unit.
a activity; (acceleration).
a. ampère, in sub-units—see footnote, p. 2093.
B magnetic induction.
C concentration; electrostatic capacity.
with subscript: molecular heat capacity.
C. Centigrade.
c velocity of light in vacuo.
c velocity; concentration.
with subscript: specific heat.
D diffusion coefficient.
d diameter; distance; (density).
d differential.
∂ partial differential.
E energy; (intrinsic energy); potential difference, especially electromotive force of voltaic cells.
with subscript: single electrode potential.
e electronic charge—charge equal and opposite in sign to that of an electron.
e quantity of electricity, especially electrostatic charge.
with subscript: single electrode potential.
e base of natural logarithms.
F Faraday's constant.
F force; (free energy—Helmholtz).
F. farad; Fahrenheit.
f acceleration; activity coefficient, *for molar concentration;* partition function.

f	function.
G	thermodynamic potential, Gibbs function, free energy—G. N. Lewis.
$\mathbf{g}$	acceleration due to gravity, standard value.
g	acceleration due to gravity, as a variable; osmotic coefficient.
g.	gram.
H	enthalpy, total heat, heat content; magnetic field strength.
H.	henry.
$\mathbf{h}$	Planck's constant.
h	height.
I	moment of inertia; ionic strength; electric current; intensity of light.
i	vapour pressure constant; van 't Hoff's factor.
$\mathbf{J}$	mechanical equivalent of heat.
J	gram-equivalent weight.
K	chemical equilibrium constant; (compressibility).
	K_s solubility product.
K.	Kelvin.
$\mathbf{k}$	Boltzmann's constant.
k	thermal conductivity; velocity constant of chemical reaction.
L	latent heat per mol; self inductance; (solubility product).
l	latent heat per g.; length; mean free path of molecules.
	with subscript: equivalent ionic conductance, " mobility ".
l.	litre.
M	molecular weight; mutual inductance; magnetic moment.
M.	molar concentration.
$\mathbf{m}$	rest mass of an electron.
m	mass.
m.	metre.
$\mathbf{N}$	Avogadro's number.
N	mol fraction.
N.	normal concentration.
n	number of mols.
	with subscript: (transport number).
	with subscript: refractive index.
P	pressure.
$[P]$	parachor.
p	pressure.
Q	quantity of electricity.
q	heat entering a system.
$\mathbf{R}$	gas constant per mol; Rydberg's constant.
R	electrical resistance.
$[R]$	*with subscript:* molecular refraction.
r	radius; (specific resistance).
	with subscript: specific refraction.
r.	Röntgen unit.
S	entropy.
s	solubility; (surface area).
T	temperature, on absolute Kelvin scale.
	with subscript: transport number.
t	time; (temperature—not on absolute scale).

U intrinsic energy.

u velocity component.
with subscript: velocity of ions.

V volume; potential, potential difference, including Volta potential.

v. volt.

v volume; velocity; velocity component.

W (work done by or on a system).

w. watt.

w work done by or on a system; velocity component.

X force component; potential gradient in electric field.

x mol fraction.

Y force component.

Z force component; g.-equivalent weight; number of molecular collisions per second; atomic number.

z valency of an ion.

α degree of electrolytic dissociation; angle of optical rotation.

$[\alpha]$ specific optical rotation.

Γ surface concentration excess.

γ ratio of specific heats; surface tension.

Δ increment.

δ very small increment.

ϵ dielectric constant; molar extinction coefficient.

ζ electrokinetic potential.

η efficiency of any process; viscosity; electrolytic polarisation, overvoltage.

θ angle of contact; temperature—not on absolute scale.

κ compressibility; specific conductance; magnetic susceptibility—volume.

Λ equivalent conductance.

λ wave length.

μ chemical potential; dipole moment; magnetic permeability.
with subscript: (refractive index).

μ. micron.

ν frequency; wave number.

Π pressure, especially osmotic pressure.

Π product.

π (electrolytic polarisation, overvoltage).

π ratio of circumference to diameter.

ρ density; specific resistance.

Σ sum.

σ diameter of molecules; (surface tension); (specific conductance).

τ time interval, especially half or mean life.

ϕ fluidity; electronic exit work function; magnetic flux.

Φ function.

χ magnetic susceptibility—mass.

ψ wave function.

Ω. ohm.

ω angular velocity; specific magnetic rotation.